VOLUME LII NUMBER 1

THE HAWAIIAN PLANTERS' RECORD

The sugar-cane leaf hopper (*Perkinsiella saccharicida*) which seriously reduced sugar yields in Hawaii for many years. Below, its principal enemy (*Cyrtorhinus mundulus*), imported from Australia and Fiji, which finally brought the pest under complete control. It was the depredations of this leaf hopper that led directly to the establishment of the Entomology Department of the Experiment Station.

FIRST QUARTER 1948

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THE HAWAIIAN PLANTERS' RECORD

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Nitrogen Effects Upon the Yield and Composition of Sugar Cane

By R. J. BORDEN

Different amounts of nitrogen applied to sugar cane have dominated the effects upon yields and composition of another 32-8560 plant crop grown at Makiki. Differences in the time of applying the nitrogen have also had their effects, and in several instances there have been significant influences from an interaction between the amounts of nitrogen and its time of application. The data have been prepared for careful study and are too numerous for a brief abstract, but reference to the summary will show the more pertinent results that were obtained from this present study.

The following presentation, which is concerned with the results from our fifth cooperative study of the effects of nitrogen upon sugar-cane crops, completes our originally authorized plan which had as its primary objective a search for guidance in nitrogen fertilization. Some progress has been made in this objective, and in addition much has been learned about the general changes in growth, development, and composition of 32-8560 cane crops under environments like those at Makiki and Waipio.

The results of this fifth study to secure reliable guidance for nitrogen fertilization of sugar cane will be presented without further introduction. At some later date we hope to bring together the most significant findings from all five studies, and so put on record those results which have been sufficiently verified and those which need still further study.

The Plan

The same area in Makiki Field 6-7 that was used in our previous study (Makiki Experiment 20 AxTN)* was also the site for the present study. The field was plowed in September 1944, left fallow for about six weeks, and given

* Reported in *The Hawaiian Planters' Record*, Vol. 49, pp. 259-312, 1945.

its final preparation and planting with 32-8560 seed on November 8, 1944. Provision was again made for ten nitrogen fertilizer differentials, randomized

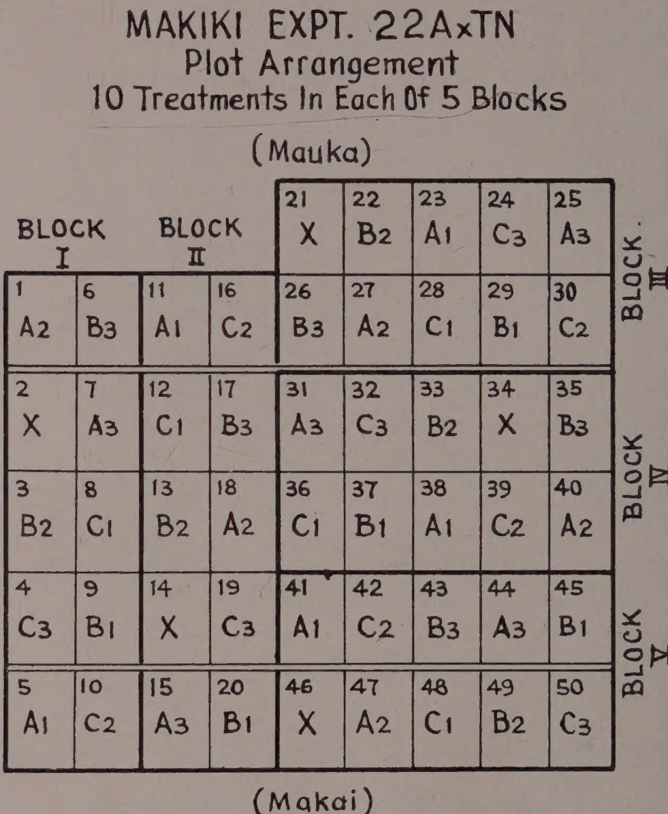


Fig. 1.

in each of five complete blocks (Fig. 1). The same 3x3 factorial plan with its three "Amounts" of nitrogen and three "Times" of application, plus one "No N" or control plot was included in each block. The fertilizer plan followed was:

PLAN OF NITROGEN FERTILIZATION

Treatment Identity	No. of Plots	At 6 wks. 12/20/44	At 4 mos. 3/15/45	At 6 mos. 5/15/45	At 11 mos. 10/15/45	Total Lbs. N
		Pounds per Acre				
A1	5	40	60	0	0	100
B1	5	40	120	0	0	160
C1	5	40	180	0	0	220
A2	5	40	0	60	0	100
B2	5	40	60	60	0	160
C2	5	40	120	60	0	220
A3	5	40	0	0	60	100
B3	5	40	60	0	60	160
C3	5	40	60	60	60	220
X	5	0	0	0	0	0

Regular irrigation rounds were given weekly to insure an ample soil moisture supply at all times. Weeds were kept under complete control.

At each three-month interval throughout the crop, and also at ten and eleven months, a crop sample of cane was cut from a ten-foot section of row in each plot. In addition a "sugar-index" sample was taken from within each of these ten-foot sections from the green tops of the first-season stalks.

Two matched stalk samples were made up from each plot at each harvest; one of these was milled in a Cuban "A" mill for the desired juice analyses, while the duplicate was carefully sub-sampled and prepared for the various laboratory analyses that were to be made. Dead canes were excluded from these samples. Principal analyses in addition to nitrogen were those for moisture, reducing sugars, sucrose, total sugars, and recoverable or commercial sugar.

Statistical Measurements

All data submitted from the several laboratories which cooperated in this study have been carefully checked and subjected to an analysis of variance to establish the degree of confidence which can be placed in the differences found between the treatments, and also to find any possible evidence of interactions between the different amounts of nitrogen and their time of application. As usually found in studies where small samples of cane are taken from field plots, the experimental errors are often quite large and many real differences may not be reliably established as treatment effects; however, if their existence can be rationalized, they may be tentatively accepted. Thus in the discussions which are to follow we have probably made some assumptions about certain measurements which we believe are sound, but which we have not necessarily proved to be specific treatment effects.

We have prepared Table I, "Coefficients of Variation", to show the extent of the uncontrolled errors in the many measurements and analyses that were made at each of the eleven different harvests, from all plots of our field test area. In Table II the statistical significance of effects of the two main treatments (A = amounts of N; T = time of application), and of their interaction (X) is given.

Thus, in spite of some rather large experimental errors, the preponderance of so many highly significant effects, especially from the different amounts of nitrogen, gives considerable confidence to our interpretation of the causes of many of the differences which were found.

Observations

Germination from the original seed pieces was exceedingly slow and spotty; some seed pieces had started to rot, so to insure a full stand in all plots, the weak spots in the rows were filled in with extra seed on November 27.

Growth at six weeks was greatly retarded and there was no evidence of stooling. Soil thermometers inserted four inches deep in the cane row showed 8 A.M. temperatures around 64-65 degrees F. with an increase to only 74-75 degrees F. by 4 P.M. These low, morning soil temperatures remained below 70 degrees F. during the entire first three months, although the afternoon soil temperatures often reached 82 degrees F. during the second and third months;

TABLE I
COEFFICIENTS OF VARIATION

Measurements	Harvest number, month, and age (months) 1 Feb. 3	2 May 6	3 Aug. 9	4 Sept. 10	5 Oct 11	6 Nov. 12	7 Feb. 15	8 May 18	9 Aug. 21	10 Nov. 24	11 Feb. 27
In tons per acre:											
For total green weight	32.8	20.6	9.9	13.9	12.6	13.5	12.1	12.0	14.2	19.8	15.9
For total dry weight	31.0	20.0	10.6	14.1	13.0	14.7	11.6	11.3	15.3	21.4	16.4
For total red. sugars	—	26.4	29.4	30.8	22.6	25.0	23.5	22.7	22.2	23.3	18.2
For total sucrose	—	29.5	13.8	14.9	14.0	15.4	12.0	12.0	15.3	22.6	17.4
For total sugars	—	26.5	12.9	14.7	13.8	14.9	11.8	12.0	14.9	22.2	17.3
For total mill. cane	—	26.9	11.3	13.8	12.1	13.9	12.2	12.5	14.8	20.2	16.5
For total comm. sugar	—	—	19.7	16.2	14.2	16.9	13.0	13.2	15.6	22.1	16.0
In pounds per acre:											
For N in total crop	28.4	16.7	13.5	12.6	11.0	14.3	15.1	16.9	15.5	18.0	17.9
In total crop:											
For % tops	—	8.0	6.4	4.8	6.2	8.4	7.8	10.7	14.6	11.3	14.6
For % moisture	.6	.9	.9	1.2	1.2	2.0	1.5	1.5	1.5	1.5	1.1
For % red. sugars	—	18.0	22.6	25.2	17.1	24.7	22.3	17.6	23.8	23.8	16.8
For % sucrose	—	11.9	6.3	3.8	3.4	3.5	3.9	3.5	4.0	4.8	3.7
For % total sugars	—	9.5	5.1	3.3	3.3	2.9	3.6	3.3	3.6	4.2	3.7
For % N	5.8	6.3	11.7	7.7	6.9	10.4	9.5	10.1	8.8	9.0	10.7
In leaves only:											
% N in leaf punch	3.0	3.4	2.8	5.8	4.9	4.9	6.3	9.0	5.2	8.5	6.7
% N in entire blades	—	3.8	4.2	5.4	4.6	7.4	8.6	7.2	7.6	8.6	11.5
% moisture in blades	—	1.3	.9	1.2	1.5	2.5	2.2	2.1	2.5	2.3	2.0
% moisture in sheaths	—	.9	1.2	1.1	1.0	1.7	1.7	1.6	1.8	1.5	1.9
% total sugars in sheaths	—	11.3	11.3	8.4	11.0	8.3	9.3	9.0	8.3	15.6	11.8
Elongating cane:											
% sucrose	—	49.3	24.6	18.6	28.6	34.2	36.0	19.6	26.1	31.9	37.0
% red. sugars	—	14.9	12.8	13.6	11.4	17.3	28.2	28.4	18.7	18.6	37.4
% total sugars	—	11.1	10.8	8.6	8.1	13.7	26.0	9.4	11.0	19.2	22.0
% amino N	—	14.6	8.7	12.6	10.2	11.9	17.0	13.9	18.5	16.1	15.4
Crusher juice:											
% N	—	15.2	15.4	9.1	9.1	16.7	21.4	9.1	22.2	10.0	9.1
Cane quality:											
Yield % cane	—	—	14.0	6.9	7.4	9.0	6.6	5.2	5.4	6.4	4.1

their effect is probably reflected in the observations made at the first harvest in February.

At three months (*February 6, 1945*): The germination which has been slow has eventually, however, resulted in a full stand, but the height of growth is extremely irregular. Very few stalks have made three visible nodes. Stooling is underway, but many of the shoots are exceedingly small and just getting started. Leaf color is good, even in the cane which has received no nitrogen fertilizer. Although three months old, the crop looks to be only about half that age.

At six months (*May 7, 1945*): There has been a large increase in the stalk population. Some of the stalks are now of fair size and have millable cane, but there is still great variability in growth within the plots. Leaves of the cane which has received only 40 pounds or less nitrogen have narrower and shorter leaf blades and leaf sheaths; the color of these leaves is also lighter than that of other

TABLE II

SIGNIFICANT EFFECTS OF TREATMENTS

A=Amounts T=Time of application X=Interaction

Measurements	Harvest number, month, and age (months) 1 Feb. 3	2 May 6	3 Aug. 9	4 Sept. 10	5 Oct. 11	6 Nov. 12	7 Feb. 15	8 May 18	9 Aug. 21	10 Nov. 24	11 Feb. 27
Tons per acre:											
Total green weight	**A**	**A**	**AT**	**AT**	**A**T	**AT**	**AX**	**A**	**A**X	**A**	**A**
Total dry weight	**A**	**A**	**AT**	**AT**	**A**T	**AT**	**AX**	**A**	**A**X	**A**	**A**
Total red. sugars	...	**A**	**A**	**A**	**A**T	**AT**	**A**T	**A**T	**A**T	**A**	**A**
Total sucrose	...	**A**	**AT**	**AT**	**A**T	**AT**	**AX**	**A**	**A**X	**A**	**A**
Total sugars	...	**A**	**AT**	**AT**	**A**T	**AT**	**AX**	**A**	**A**X	**A**	**A**
Total mill. cane	...	**A**	**AT**	**A**T	**AT**	**AT**	**AX**	**A**	**A**X	**A**	**A**
Total com. sugar	...	...	**AT**	**AT**	**A**	**AT**	**AX**	**A**	**A**X	**A**	**A**
Lbs. N in crop	**A**	**A**	**A**	**A**	**A**X	**AT**	**A**T	**A**T	**A**	**A**	**A**
Total crop:											
% tops	...	**A**	**AT**	**A**T	**A**T	**A**	**XT**	**AT**	**A**X	**A**	**AT**
% moisture	**A**	**A**	**AX**	X	ns	ns	**T**	T	**T**	A	T
% red. sugars	...	**A**	**A**	**A**	**A**	ns	**T**	**T**	**T**	ns	T
% sucrose	...	**A**	X	**A**X	**A**	ns	X**T**	**AT**	**A**	**A**	**A**
% total sugars	...	A	**AT**	**A**	**A**	A	**T**	**AT**	**A**	**A**	**A**
% N	**A**	**A**	**AT**	**A**	**A**X	**A**	**X**	**T**	A	**A**	A
Leaves only:											
% N in leaf punches	**A**	**A**	**A**	**A**	**A**	**AT**	AT	ns	A	ns	A
% N in leaf blades	...	**A**	**AX**	**A**	**A**	**AT**	AT	ns	ns	ns	ns
% moisture in leaf blades	...	**A**	**AX**	**A**	**A**	ns	A	ns	T	ns	ns
% moisture in leaf sheaths	...	**A**	**A**	**A**	**X**	A	ns	ns	ns	ns	ns
% total sugars in leaf sheaths	...	**A**	A	**A**	X	X	ns	ns	A	ns	ns
Elongating cane:											
% sucrose	...	ns	**A**	ns	ns	ns	ns	ns	ns	ns	ns
% red. sugars	...	ns	ns	**A**	ns	X	**T**	T	ns	ns	ns
% total sugars	...	ns	ns	X	ns	ns	ns	A	ns	ns	ns
% amino N	...	**A**	**A**	**A**	**A**	**A**	A	**A**	ns	ns	ns
Crusher juice:											
% N	...	**A**	**A**	**A**	**A**X	**A**	**A**	**A**	**A**	A	A
Cane quality:											
Y % C	...	...	**A**T	**X**	A	ns	X**T**	**T**	**AT**	ns	**A**

Note: Treatment identity in bold-face type indicates high significance; ns=not significant.

treatments which have now received at least 100 pounds of nitrogen per acre, but it is not yet a yellow-green. The color of Treatments B1, C1, and C2 which have already received heavy nitrogen fertilizer applications is definitely a darker green.

Stooling has been profuse and there is a very thick stand of shoots, some of which are just beginning to show a few dead spindles. Mortality will be heavy in this group of shoots which are now being shaded out by the larger primary stalks.

At nine months (August 6, 1945): The entire field now has a beautiful and uni-

form appearance. Growth irregularities are not now apparent, and there are heavy, healthy tops with good color in all treatments except X and A3. There is an almost total absence of the small shoots that were found at six months; apparently these have died and become part of the trash. A few suckers have now appeared in all plots. Unlike the 1944 crop which had lodged as early as six months, there is very little recumbent cane at this nine months' harvest. A few stalks in Treatments B and C which have made one or two feet of millable cane are found with dead tops.

At ten months (September 10, 1945): Very few of the stalks have as yet "gone down"; they show healthy vigorous tops, with, however, a somewhat lighter leaf color in all treatments except C1 and C2. Suckers are getting underway in all plots, and some of the smaller weak primary stalks now have dead tops.

At eleven months (October 8, 1945): The crop as a whole has made rapid growth. Even though the cane tonnage is now quite heavy, most stalks are still erect. More suckers have appeared. Active leaves have a similar light green color in Treatments B1, B2, C1, C2, and C3, but leaf color in all "A" treatments and in B3 and X has more yellow in it. Treatments X and A3 still have short, narrow leaves.

(October 15): Many stalks become recumbent today while the field is being irrigated.

At twelve months (November 5, 1945): Except in Treatment X, most of the stalks are now recumbent. The tops appear to be somewhat smaller. There is some evidence of tasseling but no "flags" have appeared yet. A very few suckers now have a few feet of millable stalk. There is an improved leaf color in all treatments (A3, B3, and C3) that received nitrogen last month, and for some unknown reason there is a better color from Treatment X which has never received any nitrogen fertilizer. Some primary stalks which had made only a few millable internodes were smothered out when the cane "went down" three weeks ago and their leaf spindles are now dead.

At fifteen months (February 4, 1946): Leaf color differences are not distinctly different except for Treatment X which is again quite yellow. Some plots now have a heavy tassel and the tasseled stalks have three to four strong lalas, 6 to 18 inches long. Tops appear small. Mature stalks generally have a large amount of adhering dry leaves. The sugar-index samples have to be taken from some of the small diameter stalks as almost all of the large- and medium-diameter stalks have now tasseled.

Heavy rains fell during the week preceding this harvest, as well as during the harvest.

At eighteen months (May 6, 1946): Leaf color is uniformly yellow-green in all treatments. Sugar-index samples are again taken from some small diameter, non-tasseled stalks. Lalas on tasseled stalks have made very little growth since the last harvest; only three to nine inches of millable stalk are found on these lalas.

There was dry weather during and preceding this harvest, but the weekly irrigations have prevented any wilting of the leaves. Many suckers now have considerable millable cane with large tops and there are also many new suckers (short but large diameter) coming through the trash blanket.

At twenty-one months (August 5, 1946): There is still very little millable cane on the lalas. Older suckers now contribute as much millable cane as the primary

stalks; they have large tops and a better leaf color than the primaries. The younger crop of suckers have a few feet of millable cane too. Many dead primary stalks are found — both tasseled and non-tasseled.

At twenty-four months (November 4, 1946): The primary stalks are in bad condition; stalks over 20 feet long are completely dead and dry. The greater part of the cane tonnage is now from suckers. The first-crop suckers are in excellent condition; the second-crop suckers have three to five feet of millable stalk with almost as much additional green top. The lalas have not contributed very much millable cane. All leaves are very yellow-green in color.

At twenty-seven months (February 3, 1947): This harvest is characterized by the abundance of dead canes; stalks over 20 feet long are completely dried out. Only a small per cent of the original primary stalks are still alive. Many of the first-crop suckers have tasseled; some of these have also died. Another new crop of suckers is trying to get through the heavy trash blanket. The lalas which started a year ago have still not furnished very much millable cane. There has been a big loss in cane tonnage and a definite odor of fermentation indicates a considerable deterioration of the sucrose content in all treatments.

Soil Nitrogen

Monthly Soil Analyses for Available Nitrogen:

Soil samples taken from the surface twelve inches of soil from the row middles of the five "X" plots each month were tested for available nitrogen by the Mitscherlich test. The results are shown in Fig. 2. During the first nine months

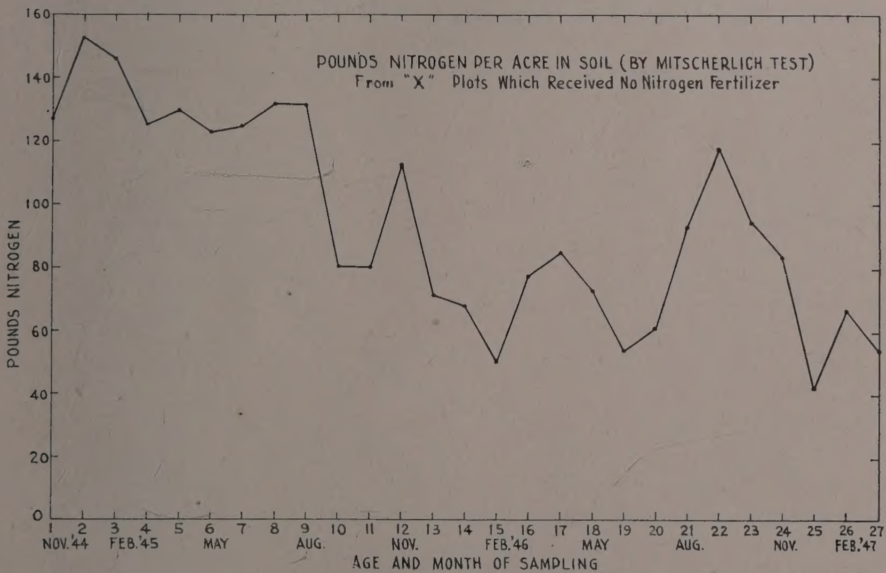


Fig. 2.

the available nitrogen supply in this unfertilized soil was high — over 120 pounds per acre; this was a much higher level than the previous crop started with on this same area. As the crop "covered-in" and its roots spread through the row

middles, there was a corresponding decrease in the amount of available soil nitrogen, with the low point being reached in February when the crop was fifteen months old. The natural nitrogen supply was somewhat erratic thereafter, with a considerable increase, however, indicated again when the crop was 21 to 24 months old.

Crop Composition

The Stalk Population:

The influence of the different amounts of nitrogen upon the nature of the stalk population is shown in Figs. 3 and 4. In the total population, there was

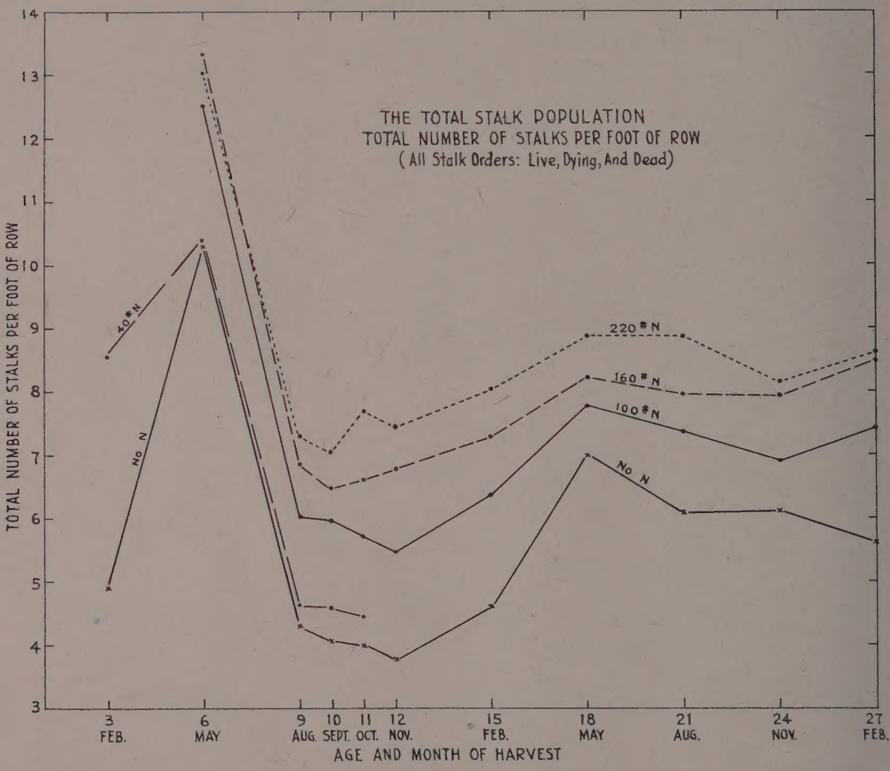
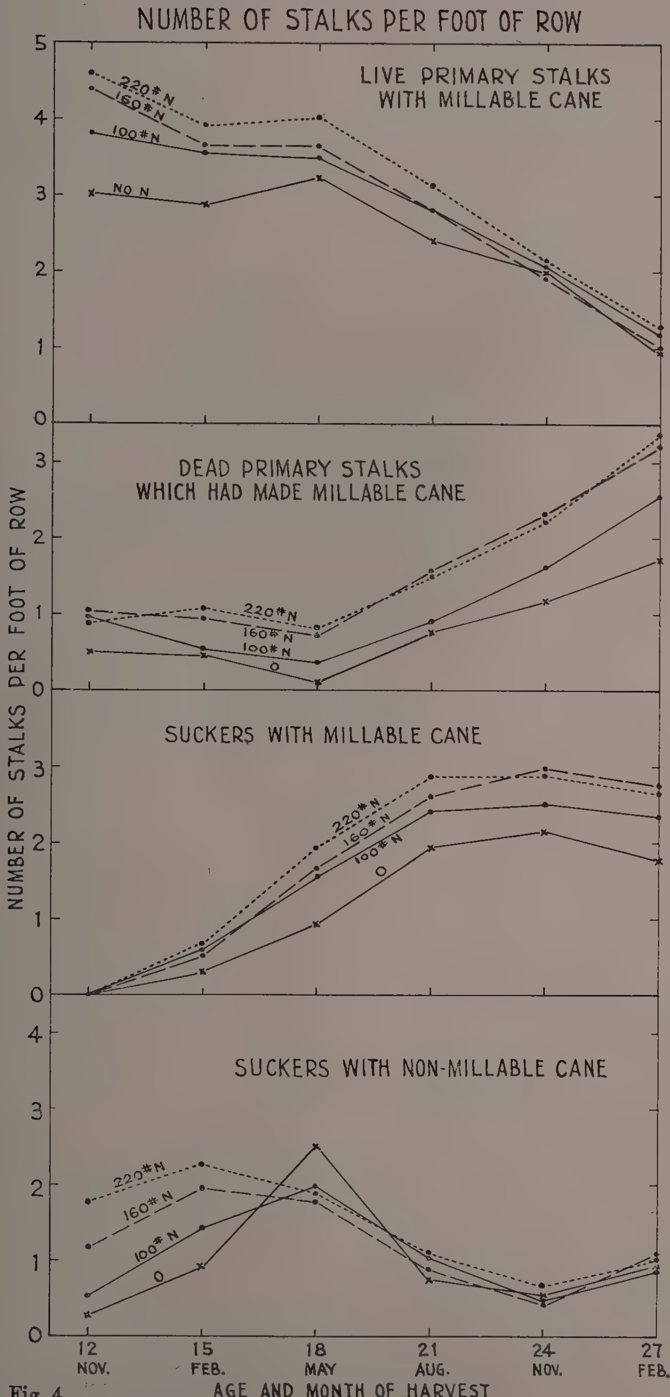


Fig. 3.

a positive relationship between the total stalk density and the amounts of nitrogen supplied for the crop. With only a few exceptions, chiefly after the crop was 21 months old, there was also a direct effect of the increases in the nitrogen supply upon the stand of living primary stalks and millable suckers. However, there is evidence that the higher nitrogen applications were the cause of more dead primaries, and also of more non-millable suckers in the earlier harvests, but not to the same degree when the crop was older. These facts are important since the quantity and quality of a sugar-cane crop are greatly influenced by the amounts of dead cane and immature suckers which are milled, as well as by the composition of the living canes.



NUMBER OF STALKS PER FOOT OF ROW
LIVE PRIMARY STALKS WITH MILLABLE CANE
220# N
160# N
100# N
NO N
DEAD PRIMARY STALKS WHICH HAD MADE MILLABLE CANE
220# N
160# N
100# N
O
SUCKERS WITH MILLABLE CANE
220# N
160# N
100# N
O
SUCKERS WITH NON-MILLABLE CANE
220# N
160# N
100# N
O
NUMBER OF STALKS PER FOOT OF ROW
12 NOV.
15 FEB.
18 MAY
21 AUG.
24 NOV.
27 FEB.
AGE AND MONTH OF HARVEST

Fig. 4.

A picture of the progressive changes in the stalk population, as a composite of all ten treatments, is given in Fig. 5. At three months there was no millable cane in sight and the ratio of shoots to primary stalks was seven to one. The maximum population was found in May at six months when an average of 3.5 stalks and 8.6 shoots was growing in each linear foot of cane row.

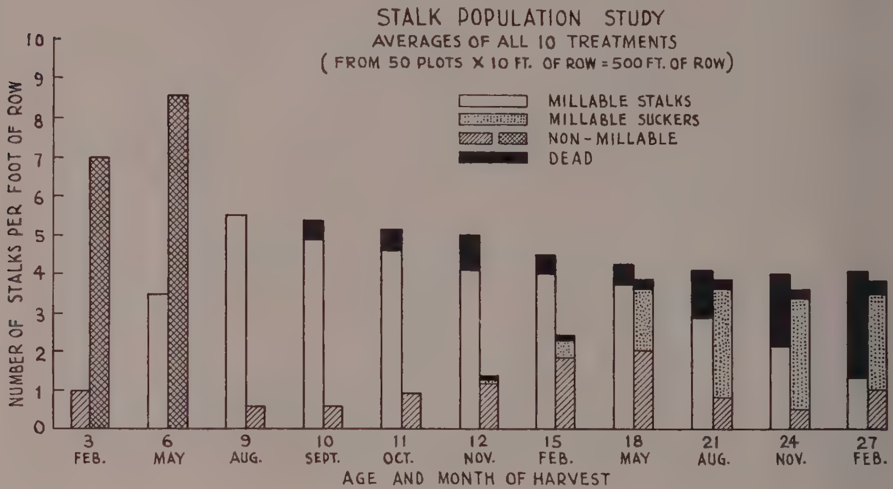


Fig. 5.

At nine months in August the total population was only half of what it had been at six months. Millable stalks had increased to 5.5 per foot of row and there were no living small shoots. Hence onlv about one-fourth of the large population of shoots that were found at six months had developed into stalks of cane; the other three-fourths had been crowded out and had died. The appearance of the first crop of suckers was now recorded in all plots.

During the next three months (September, October, November) there was very little change in the stalk population; the totals at nine, ten, eleven, and twelve months being respectively 6.2, 6.0, 6.1, and 6.3 stalks per foot of row. The mortality of stalks which had already formed some millable internodes began at ten months, with the smaller primaries being the principal victims. At twelve months a few of the smaller suckers also had dead spindles. A slight progressive increase in the number of good suckers occurred and these had formed a small amount of millable cane at twelve months.

New suckers were still being added to the population at 15 months, and more of the older ones had made millable stalk. Losses from dead stalks were not increasing, so there was a slight increase in the total stalk population. This increase was continued through the harvest at 18 months and there were then almost half as many suckers with millable cane as there were sound primaries.

After 18 months there were some distinct changes in the population. The primary stalks were dying out fast. The numbers of suckers with millable cane were not becoming any more numerous after 21 months. The following figures aptly describe this change:

Class	Stalks per foot of row At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
Sound primaries	3.7	2.9	2.1	1.3
Dead primaries	.6	1.2	1.9	2.8
Millable suckers	1.6	2.6	2.8	2.5
Non-millable suckers	2.0	1.0	.5	1.0
Dead suckers	.2	.2	.2	.3
Total population	8.1	7.9	7.5	7.9

Tasseling:

Tassel counts made in February at 15 months were incomplete as some stalks tasseled after this harvest. For instance, the average amount of tassel found in all treatments in February was 26.0 per cent; this had increased to 32.1 per cent in May. Hence we have averaged the numbers of tasseled first-season stalks found from the harvests at 18, 21, and 24 months and summarized these averages as follows:

Treatment	% Tassel
X	32.3
A1	28.8
B1	27.2
C1	27.3
A2	36.9
B2	34.0
C2	23.6
A3	33.6
B3	33.5
C3	29.7

Treatments	Lbs. N applied	% Tassel
X	0	32.3
A1, A2, A3	100	33.1
B1, B2, B3	160	31.6
C1, C2, C3	220	26.9

Treatments	N application completed	% Tassel
A1, B1, C1	At 4 mos.	27.8
A2, B2, C2	At 6 mos.	31.5
A3, B3, C3	At 11 mos.	32.3

The heavier applications of nitrogen reduced the amount of tasseling, more especially where the total applications were completed early.

Per Cent Tops (Table I in Appendix):

Fifty per cent of the total green weights harvested at six months was composed of leafy tops, but within the next three or four months this figure was reduced to 25 per cent. Further crop development brought this percentage figure to slightly under 17 per cent at twelve months and down to 10.6 per cent at 24 months.

Differences in nitrogen applications have had some significant effects upon this per cent tops in green weight. The percentage was generally higher from the lower nitrogen treatments, and also from the plots in which there were delayed applications of the nitrogen fertilizer. For example:

Nitrogen totals	Average per cent tops in green weight At 15 mos.	18 mos	21 mos.	24 mos.
No N	19.2	21.6	18.2	13.1
100 lbs. N	16.3	16.4	14.0	10.7
160 lbs. N	14.6	13.9	13.2	10.4
220 lbs. N	14.7	13.9	12.7	9.8
L.S.D.*	.9	1.2	1.5	.9

*L.S.D. = least significant difference between averages recorded; also referred to as M.d.r. or minimum difference required for P at .05.

Time of application	At 15 mos.	18 mos.	21 mos.	24 mos.
All N by 4 mos.	13.6	13.8	13.0	10.0
Last N at 6 mos.	14.1	14.5	13.1	10.9
Last N at 11 mos.	17.9	15.9	13.8	10.0
L.S.D.	.9	1.2	ns	ns

In terms of total tonnages of green tops per acre, we can get a better idea of the total amount of green cane which was active in photosynthesis at the different growth stages.

AVERAGE TONS PER ACRE OF GREEN TOPS (ALL TREATMENTS)

At 3 mos. in Feb.	At 6 mos. in May	At 9 mos. in Aug.	At 10 mos. in Sept.	At 11 mos. in Oct.	At 12 mos. in Nov.	At 15 mos. in Feb.	At 18 mos. in May	At 21 mos. in Aug.	At 24 mos. in Nov.	At 27 mos. in Feb
2.5	19.2	22.2	19.1	17.9	16.0	15.1	16.6	15.1	10.9	7.3

The maximum amount was found in this crop at nine months (in August) and its amount (22.2 tons) compares very closely with the maximum of 22.6 tons that were also found at nine months (in February, however) in the 1944 crop. Between nine and twelve months there was a decrease of almost 30 per cent in the average tonnage of green tops. A very small increase at 18 months was due to the large tops on the suckers which were then in very active growth.

The effect of different amounts of nitrogen on the tonnage of green tops is definite; the higher amounts produced more tops.

Pounds N applied by 6th month	Tons green tops per acre							
	At 6 mos.	At 9 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	11.4	10.1	8.4	8.1	10.2	10.2	7.7	5.5
100	20.4	20.8	14.6	11.8	14.2	13.7	9.9	7.3
160	24.0	25.5	18.3	13.9	15.1	13.9	11.0	7.7
220	21.3	28.6	20.7	17.1	18.3	16.7	12.4	7.7

The effects from delayed nitrogen applications are not as clear as the effects from the different amounts of nitrogen. For example, from harvests after twelve months when the 220-pound nitrogen totals were identical, any real effect from the delayed application is doubtful.

220 lbs. N applied as follows				Tons green tops harvested per acre					
At 1½ mos.	At 4 mos.	At 6 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
40	180	0	0	21.1	17.6	18.9	19.1	13.0	7.9
40	120	60	0	20.3	16.5	17.6	14.3	11.7	7.4
40	60	60	60	17.5	19.8	20.0	17.9	11.4	7.4

Crop Analyses

Per Cent Moisture in Total Green Weight, Leaf Sheaths, and Leaf Blades (Tables 2, 3, and 4 in Appendix):

The average moisture contents in the total green weights, leaf sheaths, and leaf blades in this 32-8560 crop are shown in Fig. 6. The general levels dropped rapidly between six and ten months but much more slowly thereafter. The three lines show quite similar trends although there are a few discrepancies. For instance, the slight drop in the moisture content of the total green weight between 12 and 15 months is in contrast to the slight increases in the leaf sheaths and blades during this same period; and from 18 to 21 months, the drop in leaf-blade moisture is not similarly found in the leaf sheaths or total green weights.

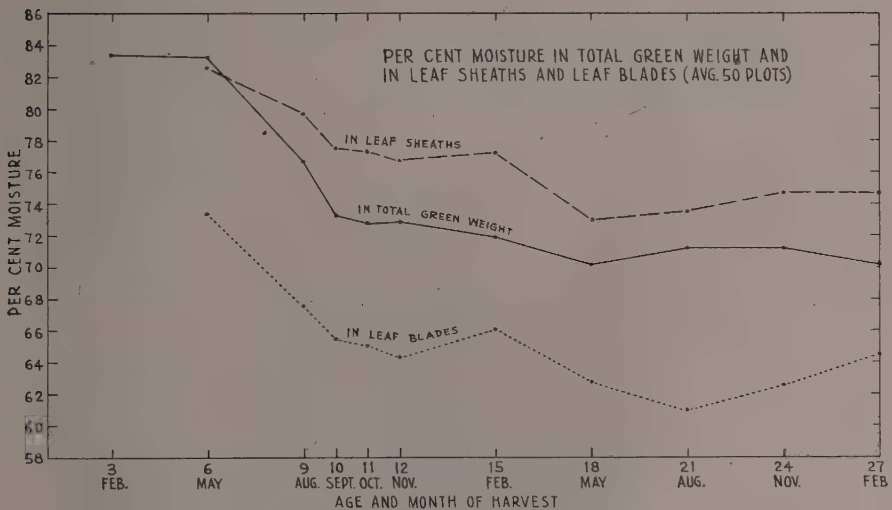


Fig. 6.

The effects of nitrogen on the percentages of moisture in the total green weight were very definite during the early growth stages (Fig. 7); the heavier fertilized canes had the higher moisture content at three, six, and nine months, but not thereafter. In the leaf sheaths and leaf blades, a higher moisture content was still coming from the higher nitrogen applications at eleven months, but thereafter this nitrogen effect was apparently lost.

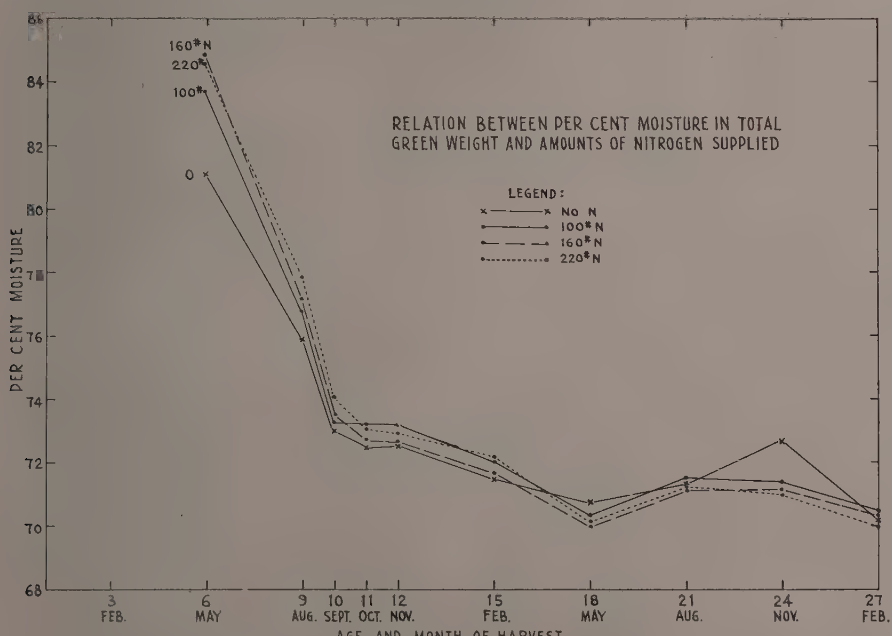


Fig. 7.

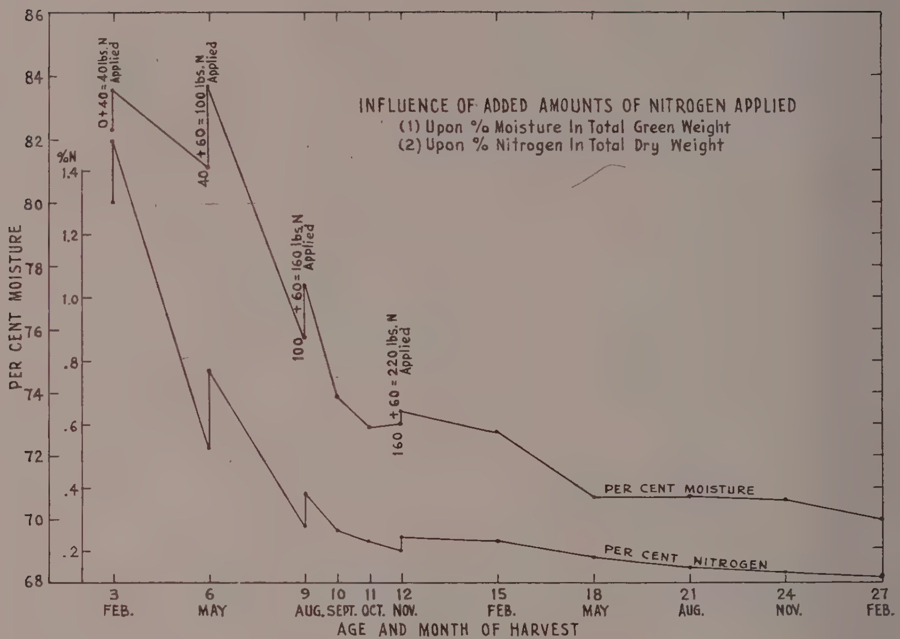


Fig. 8.

Each application of nitrogen produced an increase in the moisture content of the total green weight, but the extent of this increase was progressively less for each successive application (Fig. 8).

At 15 and 18 months an effect from the time of application of the nitrogen was found, and the moisture percentage in the total green weight was then somewhat higher when the last application had been given at eleven months. At 21, 24, and 27 months however, this effect from time of application was apparently reversed, and in this instance the moisture content for cane which had received its final application at four months was slightly higher than that which was fertilized later.

Per Cent Reducing Sugars (Tables 5 and 6 in Appendix):

Almost immediately after twelve months, the concentration of reducing sugars in the total dry weight dropped below 2 per cent and fluctuated only slightly from 1.5 per cent thereafter. After the tenth month the per cent reducing sugars in the active elongating cane paralleled that in the total dry weight, at only a slightly lower level (Fig. 9).

During the first eleven months, the percentages of reducing sugars were consistently increased by increases in the total nitrogen applications, but thereafter this influence from the different amounts of nitrogen was not significant.

Lbs. N applied	Per cent reducing sugars in total dry weight				
	At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.
40	5.68	2.52	2.07	1.78	—
100	8.39	3.84	2.42	2.44	2.25
160	10.02	4.53	2.97	2.51	2.11
220	10.08	6 00	4.04	2.82	2.23

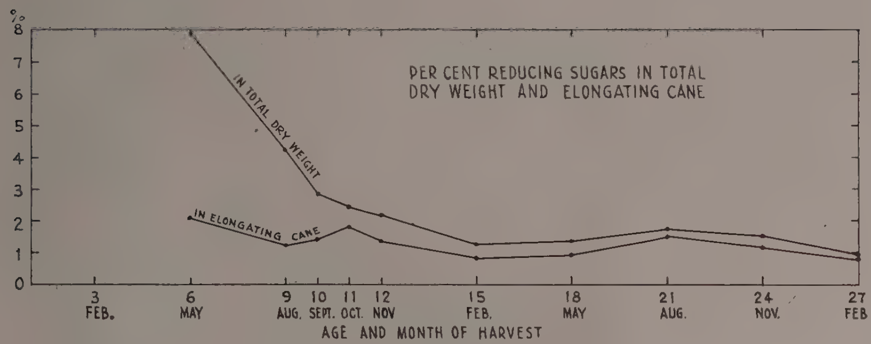


Fig. 9.

At 15 and 18 months there were significant increases from the late nitrogen applications. However, at 21, 24, and 27 months, these effects of time were reversed just as they were on the per cent moisture, and the earlier fertilized canes then had the higher percentages of reducing sugars. The following are interesting relationships between moisture and reducing sugars:

Time of application	Moisture and reducing sugars in total crop — At 15 mos. % Moist.	At 15 mos. % Rd. S.	At 18 mos. % Moist.	At 18 mos. % Rd. S.	At 21 mos. % Moist.	At 21 mos. % Rd. S.	At 24 mos. % Moist.	At 24 mos. % Rd. S.	At 27 mos. % Moist.	At 27 mos. % Rd. S.
All N by 4 mos......	71.3	1.09	69.7	1.27	72.0	2.04	71.4	1.52	70.4	1.01
Last N at 6 mos.....	71.4	1.16	69.8	1.29	71.1	1.78	71.2	1.46	70.5	.95
Last N at 11 mos....	73.0	1.56	70.8	1.57	70.6	1.42	70.9	1.44	69.7	.86
L.S.D..........	.8	.21	.8	.18	.8	.31	ns	ns	.6	.12

Per Cent Sucrose (*Tables 7 and 8 in Appendix*):

A rapid increase in the concentration of sucrose in this crop continued for 15 months and then levelled off without significant increase thereafter. Hence it would seem that, in contrast to our 1944 crop which showed this evidence of primary stalk maturity at twelve months, the present crop because of its slow start took 15 months to reach a similar degree of maturity.

The same inverse relationship between the percentage of sucrose and the percentages of moisture and nitrogen in the total crop was found again (Fig. 10).

The effect from the different nitrogen fertilizer applications upon the per cent sucrose in the total dry weight was highly significant at several harvests. At six, nine, ten, and eleven months there were progressively lower concentrations of sucrose for each increase in nitrogen applied. At 12 and 15 months there were no proved effects from the different amounts, but there were lower concentrations when the last application was made at eleven months and this "time" effect was carried over to 18 months. At 18 months and thereafter another complete reversal of effects from amounts of nitrogen occurred, with slightly higher percentages of sucrose then being found in the more liberally fertilized crop.

Lbs. N applied	Per cent sucrose in total dry weight — At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
40	12.4	30.9	35.3	38.8	—	—	—	—	—	—
100	9.7	28.4	34.3	35.6	37.4	41.9	40.8	40.4	41.1	44.9
160	8.5	27.8	33.8	35.2	37.8	42.3	43.4	41.8	41.7	45.1
220	7.0	26.1	31.8	34.0	36.9	42.6	43.3	42.0	42.0	46.3

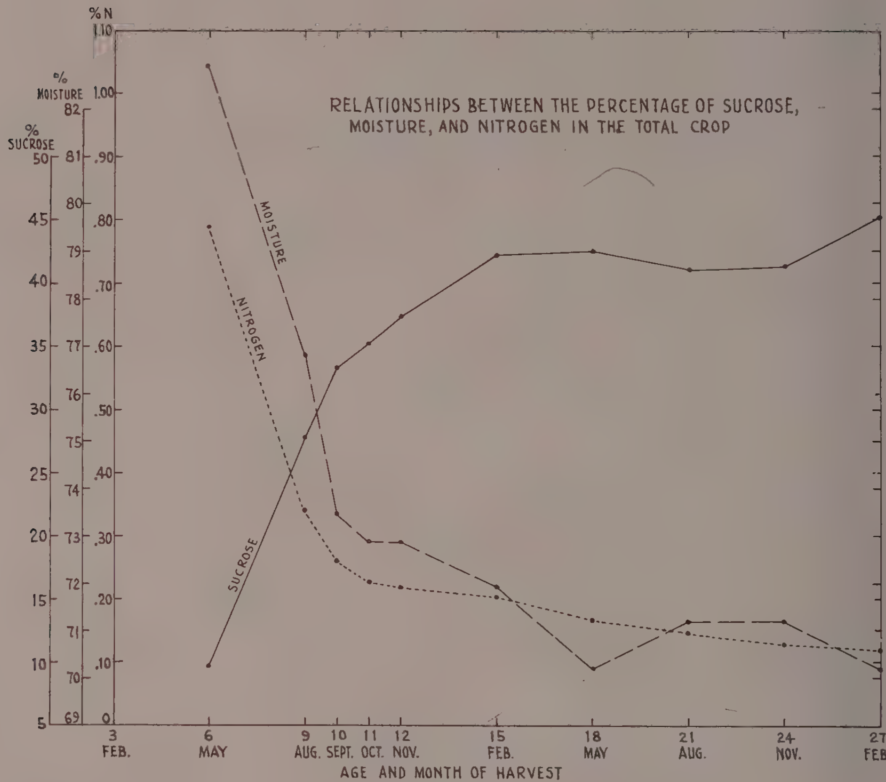


Fig. 10.

An average increase (from .73 to 2.53 per cent) in the concentration of sucrose in the elongating cane occurred between 12 and 15 months (November to February). This increase was associated with a pronounced average decrease (from 1.39 to .85 per cent) in the concentration of reducing sugars, and also with the definite slowing down in the rate at which additional growth was being made by the crop. A similar correlation was found for these same percentages in the total dry weights.

Per Cent Total Sugars (Tables 9, 10, and 11 in Appendix):

From Fig. 11 we note several things about the percentage of total sugars in the crops which were grown: (1) the low percentages in the elongating cane increased very little throughout the crop; (2) in the leaf sheaths the concentration varied only slightly from ten per cent during the first 15 months but then took a definite upward jump, which may be a seasonal effect brought about by more favorable sunlight and temperature conditions; and (3) in the total dry weight the changes were almost exactly those we noted for the percentages of sucrose.

The nitrogen effects were chiefly those from the different amounts applied, and in most respects these were similar to those we recorded for the effects on the per cent sucrose. At six months the concentration of total sugars in the total

dry weight from the 220-pound nitrogen applications was lower (17.4 per cent) than from the 100-pound applications (18.6 per cent); conversely the leaf sheaths from the 220-pound plots had higher total sugars (13.7 per cent) than the sheaths from the 100-pound treatments (11.0 per cent).

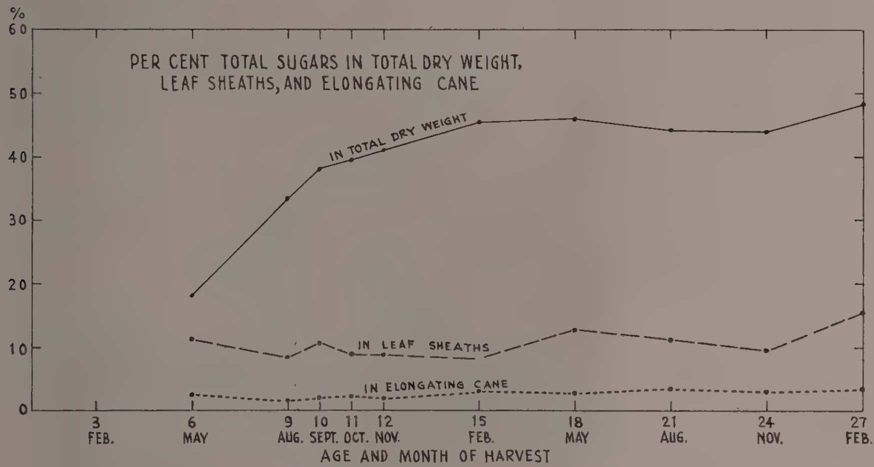


Fig. 11.

At nine to twelve months inclusive differential effects from the 100-, 160-, and 220-pound nitrogen treatments were not significant on the per cent total sugars in total dry weight, although the crop from the X plots was definitely lower than the fertilized canes. The effect on the per cent total sugars in the leaf sheaths was again indicative of the "more nitrogen — more total sugars" relationship previously found in leaf-sheath analyses, e.g.:

Lbs. N applied	Per cent total sugars in leaf sheaths At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos
0	8.73 ns	9.46 ns	7.92	8.03
40	8.84	9.41	8.28	—
100	8.36	10.38	8.51	8.76
160	8.32	11.46	9.44	8.92
220	9.66	12.59	10.05	9.50

At 15 and 18 months a "time" effect was found on sugars in total dry weight, and a lower concentration was carried by the cane which had received the late or eleven months' application of nitrogen fertilizer. After 15 months the larger amounts of nitrogen finally produced canes with increased percentages of *total* sugars.

Lbs. N applied	Per cent total sugars in total dry weight At 15 Mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	44.7	44.1	40.8	41.1	45.7
100	45.5	45.4	44.3	44.7	48.3
160	45.8	47.0	45.7	45.4	48.3
220	46.1	46.9	46.0	45.7	49.6
L.S.D.	ns	1.1	1.2	1.3	1.3

Per Cent Total Nitrogen (Tables 12 to 16 Inclusive in Appendix):

The general relation between the five different analyses for nitrogen is shown in Fig. 12. The per cent N in the leaf-punch samples taken at ten months was low.

A slight increase at eleven months and a further increase at twelve months was registered by all treatments, including the "no-N" plots. The low concentrations reached at 18 months show a very complete utilization of the nitrogen that was available to this crop.

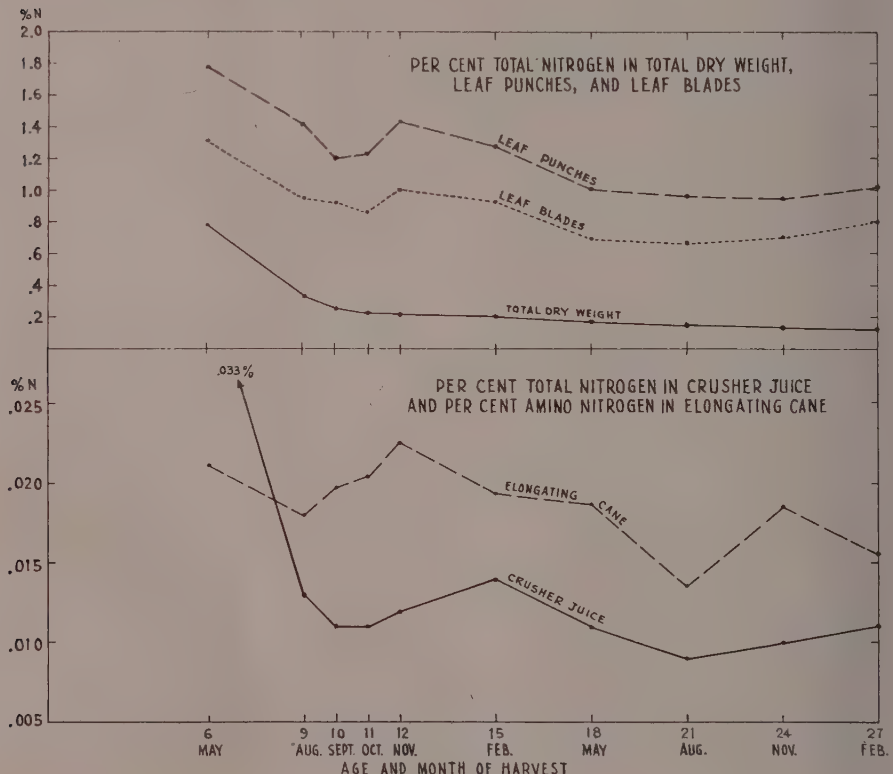


Fig. 12.

The nitrogen in the entire leaf blades paralleled that in the leaf-punch samples. In the total dry weight, the concentration decreased rapidly in the first ten or eleven months but very little more thereafter.

Amino nitrogen in the elongating cane increased between nine and twelve months, and in this respect was about two months ahead of a similar increase found in the crusher juice nitrogen content. The low point in both of these analyses came at 21 months in August.

The increased amounts of applied nitrogen had their direct influences on the percentages of nitrogen found in all measurements. This was especially true during the first 15 months for analyses made from the leaf-punch samples (Fig. 13) and leaf blades, but the nitrogen treatments continued to exert their

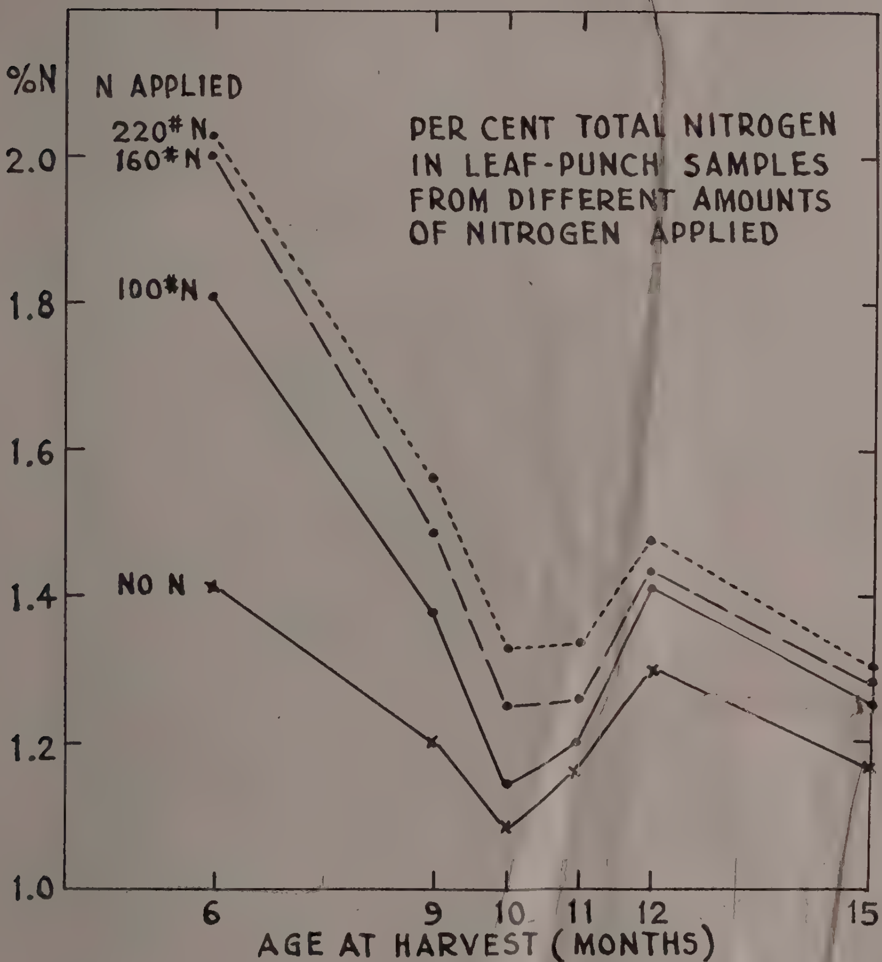


Fig. 13.

effects on the percentages of N in the total dry weight, in the crusher juices (Fig. 14), and in the elongating cane.

Amino nitrogen in the elongating cane especially from six to 18 months was directly affected, i.e. increased, by each increase in applied nitrogen fertilizer.

Lbs. N applied	P.P.M. amino nitrogen in elongating cane									
	At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	131	123	149	165	172	154	156	122	180	151
40	152	176	173	183	—	—	—	—	—	—
100	197	185	190	200	227	185	178	123	174	153
160	262	189	217	219	235	203	198	141	198	154
220	298	212	224	228	239	208	195	145	187	163

The uptake of nitrogen by this crop was quite rapid. For instance our analyses made on plant materials collected *before* and again *after* the application

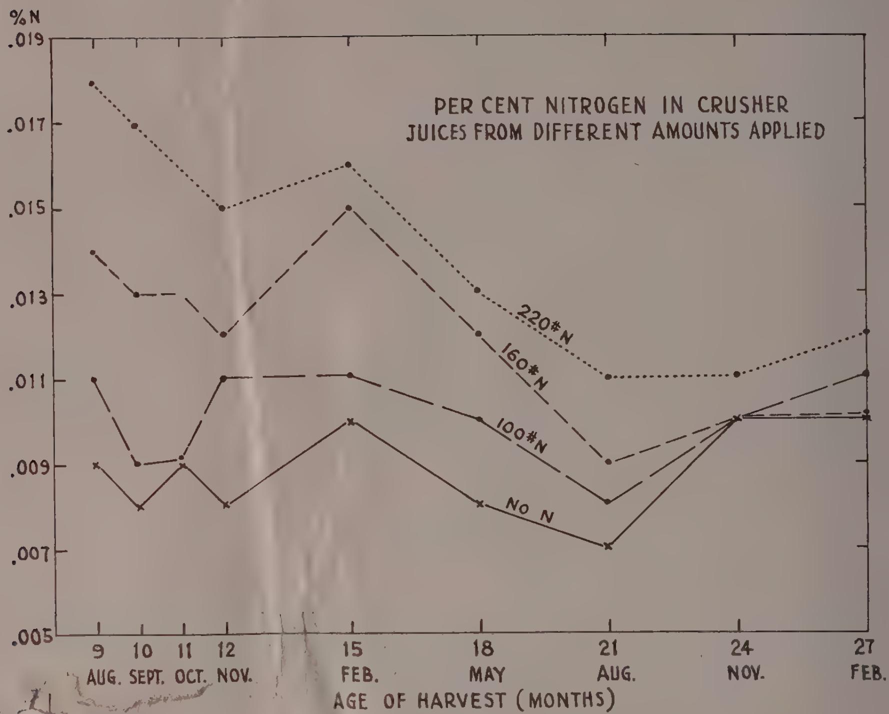


Fig. 14.

of 60 pounds of nitrogen at eleven months for Treatments A3, B3, and C3 show that a considerable amount of the added nitrogen was concentrated within the crop during this short period of only four weeks.

Treat-ment	Per cent nitrogen in crop **before** and **after** fertilizing: % N in Total dry Wt. Before	After	% N in Leaf punch Before	After	% N in Leaf Blades Before	After	% N in Juice Before	After	P.P.M. Amino N in Elon. Cane Before	After
A3	.177	.226	1.08	1.48	.78	1.17	.007	.012	183	233
B3	.198	.228	1.19	1.50	.81	1.15	.009	.013	200	244
C3	.230	.249	1.28	1.54	.89	1.16	.011	.013	226	256
X*	.197	.184	1.16	1.30	.80	.95	.009	.008	165	172

*Treatment X received no nitrogen fertilizer; its data are recorded here to show the corresponding changes in non-fertilized cane.

Time of application, particularly when the last application was made at eleven months, increased the nitrogen in the leaves at 12 and 15 months, and this effect was carried over into the total dry weight at 18 months.

In Fig. 15 the percentages of nitrogen in the leaf-punch samples during the critical growth period from six to eleven months are shown for the three differences in time of application for the different nitrogen totals. Although the levels were slightly different between the three groups, there is no doubt of the effects from the total amounts.

Since our main objective in this study was to secure guidance in nitrogen fertilization, and since we need such guidance especially at ten or eleven months

so that nitrogen deficiencies will be identified and nitrogen excesses avoided for the immediate crop, a study of these nitrogen data from the harvests at six,

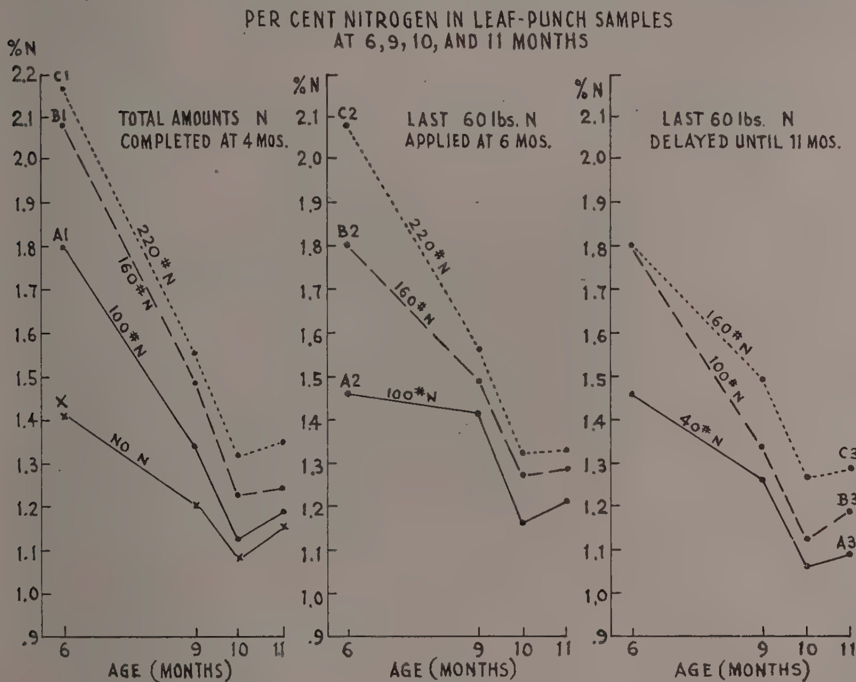


Fig. 15.

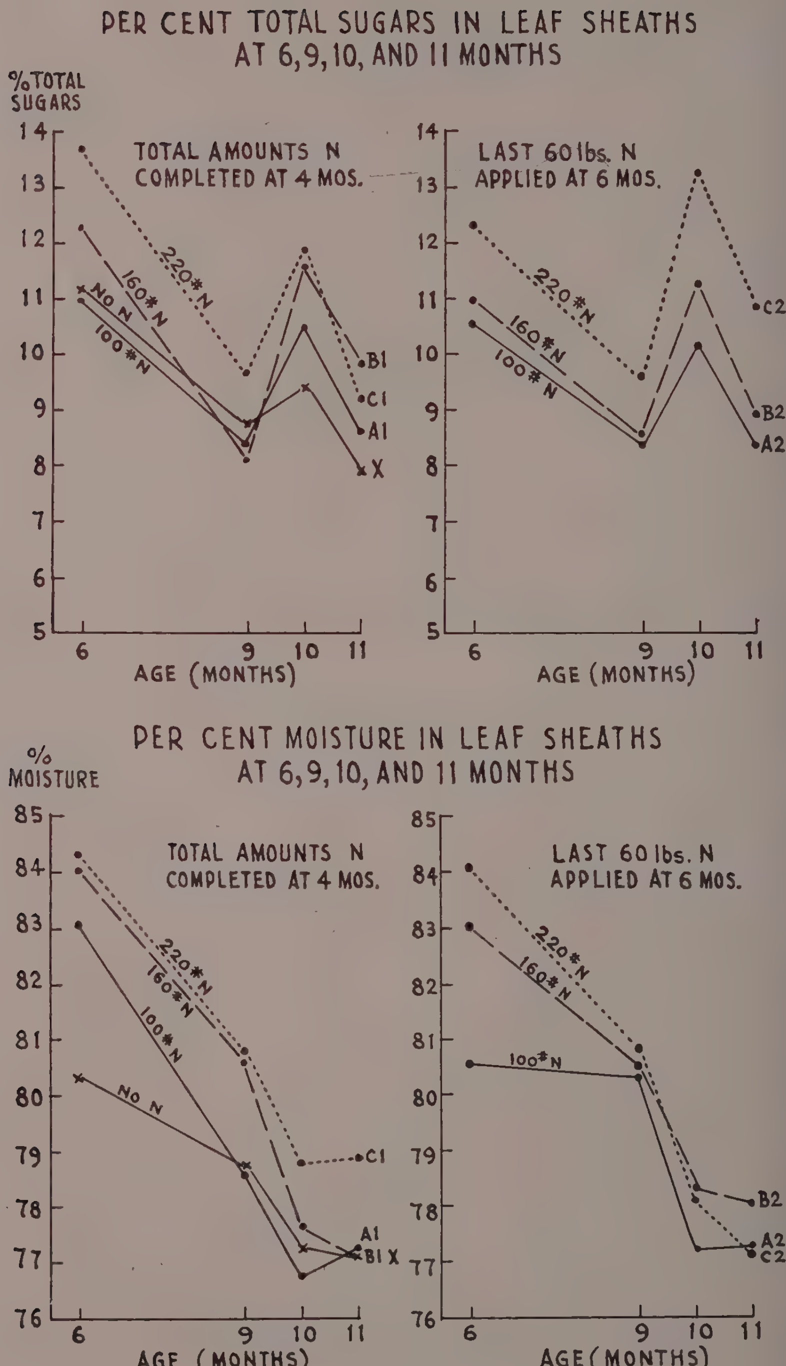
nine, ten, and eleven months is in order. In this instance we give special attention to Treatments A1 and B2 which eventually produced the best average sugar yield for the 18, 21, and 24 months' harvests from their respective amounts of nitrogen (100 and 160 pounds) applied.

Treatment	Per cent N in total dry Wt. At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	Per cent N in leaf punches At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.
A1—100#	.766	.276	.218	.198	1.80	1.34	1.12	1.19
B2—160#	.766	.358	.267	.230	1.80	1.49	1.27	1.28

Treatment	Per cent N in leaf blades At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	Per cent N in crusher juice At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.
A1—100#	1.34	.87	.90	.81	.027	.010	.009	.009
B2—160#	1.34	1.03	.96	.89	.027	.013	.012	.011

Treatment	Per cent amino N in elongating cane At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.
A1—100#	.0197	.0177	.0182	.0200
B2—160#	.0197	.0189	.0223	.0226

Since Treatment B2 (160 pounds N) produced more commercial sugar than A1 (100 pounds N), it is obvious that the levels of nitrogen found in the samples



PER CENT TOTAL SUGARS IN LEAF SHEATHS
AT 6, 9, 10, AND 11 MONTHS
% TOTAL SUGARS
TOTAL AMOUNTS N
COMPLETED AT 4 MOS.
LAST 60 lbs. N
APPLIED AT 6 MOS.
220# N
160# N
100# N
NO N
B1
C1
A1
X
C2
B2
A2
AGE (MONTHS)
PER CENT MOISTURE IN LEAF SHEATHS
AT 6, 9, 10, AND 11 MONTHS
% MOISTURE

Fig. 16.

from A1 at eleven months were too low, because an extra 60 pounds of N applied at six months, which brought the total N to 160 pounds, increased the sugar yields. Similarly, the levels found in Treatment B2 at eleven months were also too low, because when still another 60 pounds of N were applied at eleven months the new total of 220 pounds (for Treatment C3) gave a still further increase in the sugar yields. Hence at the age of eleven months the following total nitrogen concentrations were found to be *inadequate* to produce maximum sugar yields thereafter —.230 per cent in the total dry weight, 1.28 per cent in the leaf-punch samples, .89 per cent in the leaf blades, .011 per cent in the crusher juices, and .0226 per cent amino nitrogen in the elongating cane. Unfortunately the limits of our plan made it impossible to identify *adequate* levels above which no further increase in yield might be expected.

The Primary Index

A study of Clement's "primary index" was continued on leaf-sheath samples taken at each harvest. After the first year of growth in this crop, it was not always possible to find in our sample row sufficient *average* stalks which had not tasselled and so leaf-sheath samples had to be taken from some of the smaller stalks on which the required third to sixth leaves could be identified. Our special interest, however, was in the primary index values at six, nine, ten, and eleven months and for these harvests our samples were truly representative of the normal healthy stalks in the crop. These are given below:

THE PRIMARY INDEX
(Per Cent Total Sugars in Leaf Sheaths)

Lbs. N applied	At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.
0	11.2	8.7	9.5	7.9
40	10.6	8.8	9.4	8.3
100	11.0	8.4	10.4	8.5
160	12.4	8.3	11.5	9.4
220	13.7	9.7	12.6	10.0

The higher nitrogen applications certainly produced canes carrying higher concentrations of total sugars in their leaf sheaths.

The averaged analyses for all separate harvests are given in Appendix Tables 11, 3, and 13. In Fig. 16 the primary indices or the per cent total sugars in leaf sheaths, and the corresponding percentages of moisture, from the six to eleven months' harvests are shown for two groups: one in which the total nitrogen applications were completed at four months and the other in six months. With few exceptions these graphs show that higher concentrations of total sugars in leaf sheaths as well as higher percentages of moisture came from the heavier applications of nitrogen, and in this respect there is positive correlation with the percentages of N which we found in the leaf-punch samples. Hence there is again evidence of the same *positive* relationship between the nitrogen in leaf-punch samples and the moisture and total sugars in leaf sheaths that we recorded from the 1944 crop. Furthermore, during this same period, the actual increases made by the crop in its total dry weight were greater from the more liberally fertilized canes which had these higher nitrogen, higher moisture, and higher primary index values, so apparently the higher primary indices which were

found at six months did not indicate that sugars were then being stored in the leaf sheaths at the expense of growth.

AVERAGE MONTHLY GAINS IN TOTAL DRY WEIGHT

(Tons/Acre)

Lbs. N applied	Between 6 and 9 mos. (Total)		Between 9 and 10 mos.	Between 10 and 11 mos.
0	(3.9)	1.3	2.6	1.5
40	(8.1)	2.7	1.4	0.7
100	(10.7)	3.6	3.3	1.6
160	(14.8)	4.9	3.5	2.2
220	(17.4)	5.8	4.6	5.3

Finally, since the highest yields of recoverable sugar came from the "C" plots, it must be inferred that the higher percentages of total sugars and moisture in leaf sheaths, and the higher nitrogen in the leaves of the "C" treatments at ten and eleven months, are preferred indices over lower amounts of these factors in the first year's growth.

RELATION BETWEEN EARLY PRIMARY, MOISTURE, AND NITROGEN INDICES AND THE FINAL SUGAR YIELDS

		Primary Index		Moisture Index		N Index		T.S.A.			
Treatment	Lbs. N applied by the 6th mo.	At 10 mos.	At 11 mos.	At 10 mos.	At 11 mos.	At 10 mos.	At 11 mos.	At 18 mos.	At 21 mos.	At 24 mos.	Avg. T.S.A. (3 harvests)
A1	100	10.5	8.6	76.7	77.2	1.12	1.19	10.6	9.4	9.6	9.9
B1	160	11.6	9.9	77.6	77.1	1.23	1.24	12.4	9.3	10.1	10.6
C1	220	11.9	9.3	78.8	79.0	1.32	1.35	14.1	12.6	14.9	13.9
A2	100	10.2	8.4	77.2	77.3	1.16	1.21	9.5	9.9	9.8	9.7
B2	160	11.3	9.0	78.4	78.1	1.27	1.28	13.3	11.2	13.1	12.5
C2	220	13.3	10.8	78.1	77.3	1.32	1.33	14.2	12.0	12.0	12.7
A3	40	9.4	8.3	76.3	76.2	1.06	1.08	9.0	8.4	10.1	9.2
B3	100	10.5	8.6	76.7	77.2	1.12	1.19	11.7	12.6	12.1	12.3
C3	160	11.3	9.0	78.4	78.1	1.27	1.28	15.1	15.6	14.5	15.1

Yields

Yields of Total Green Weight, Dry Weight, and Millable Cane (*Tables 17, 18, and 19 in Appendix*):

Fig. 17 shows the general manner in which this crop developed. The most rapid increases occurred between three and nine months, and as early as nine months this crop had made over 63 per cent of the maximum yield of millable cane which it was to reach at 21 months; the crop actually lost weight after 21 months.

Differences in the rate of increase in yields by this crop are again largely the effect of age. For example, we have recorded an average gain of 20.2 tons of millable cane for the three to six months' period of growth which came from February to May, whereas during the similar calendar months of the following year when the crop was 15 to 18 months, the gain was only 9.3 tons. Similarly for the two consecutive May-to-August-growth periods, an average gain of 39.1 tons of millable cane was secured from cane between six and nine months of age, as compared with only 3.3 tons when the crop's age was 18 to 21 months.

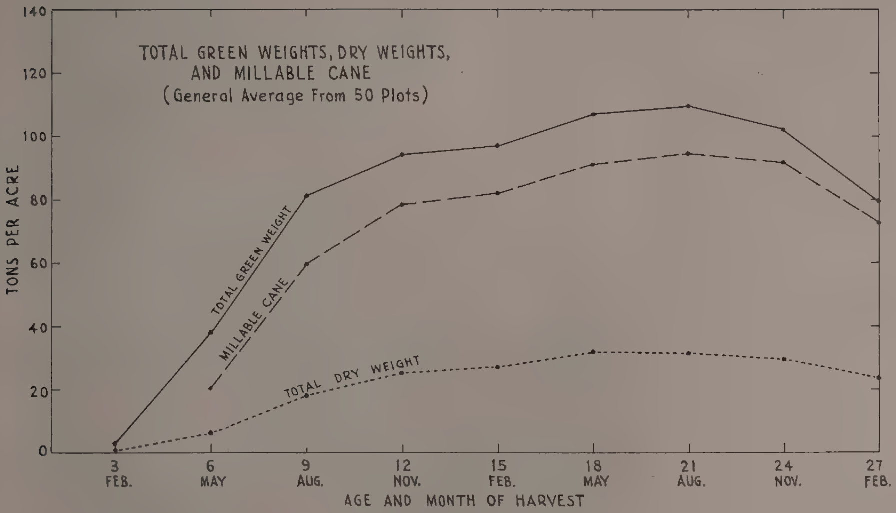


Fig. 17.

GAINS OR LOSSES IN AVERAGE WEIGHTS
(Tons/Acre)

Total Yields	From: Nov. to Feb. 0-3 mos.	Feb. to May 3-6 mos.	May to Aug. 6-9 mos.	Aug. to Nov. 9-12 mos.	Nov. to Feb. 12-15 mos.	Feb. to May 15-18 mos.	May to Aug. 18-21 mos.	Aug. to Nov. 21-24 mos.	Nov. to Feb. 24-27 mos.
Green Wt.......	+2.5	+36.2	+42.3	+13.6	+2.3	+10.5	+2.0	−6.8	−22.7
Mill. Cane......	0	+20.2	+39.1	+19.5	+3.3	+ 9.3	+3.3	−2.6	−19.2
Dry Wt.........	+0.4	+ 5.8	+12.4	+ 7.0	+1.6	+ 4.8	−0.5	−1.9	− 5.8

The influence of the different amounts of nitrogen on these yields was direct and similar, and increases resulted from each additional increment of nitrogen applied. This is nicely shown by the following tabulation of the average effects from the applied nitrogen upon the millable cane yields.

Lbs. N applied	Average yields of millable cane: At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	20.4	27.5	32.1	33.5	34.1	36.9	45.4	51.1	36.9
40	36.1	39.5	42.9	—	—	—	—	—	—
100	55.2	60.4	67.9	70.5	69.9	77.9	83.9	82.2	64.6
160	73.8	76.6	84.1	85.6	88.1	98.0	98.5	96.5	74.6
220	80.0	86.2	101.2	95.5	104.4	116.4	118.1	111.1	91.5

There were also some rather definite effects on yields secured at nine to twelve months from differences in the time of applying the nitrogen. This effect was highly significant even though there was only a two months' difference in the time of application. To illustrate, we have tabulated the effect of time on the total dry weights.

Last N application	Average tons per acre of total dry weight: At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.
At 4 mos....................	23.0	26.9	29.6	30.5
At 6 mos....................	19.9	23.7	26.9	28.6

At 15 months the effect from time of application was modified by the amounts applied. For instance, there was a definite loss in yields of total green and dry weights and in millable cane when the last 60 pounds of a total application of only 100 pounds of N was held off beyond four months, but when the last 60 pounds of a total 160- or 220-pound application was held off even until eleven months, there was no similar loss in yield from such late application, probably because these more liberally fertilized plots received a more adequate amount of nitrogen (100 pounds or more) within the first four months.

At 21 months the interaction between amounts of nitrogen and its time of application appears to be somewhat different from that at 15 months. In this case, although a loss from the longer delay to eleven months for the final application in the 100-pound N treatments was still found, there is a suggestion that a gain was secured in the 160- and 220-pound treatments. These differential effects are illustrated by the following comparisons:

AVERAGES FROM 5 REPLICATES

Time of N application	TCA at 15 mos. Total N applied 100 lbs.	160 lbs.	220 lbs.	TCA at 21 mos. Total N applied 100 lbs.	160 lbs.	220 lbs.
All N by 4 mos.	90.2	86.1	102.4	86.6	87.9	114.8
Last 60# at 6 mos.	59.0	93.1	102.6	90.6	99.8	109.5
Last 60# at 11 mos.	60.4	85.2	108.3	74.5	107.8	129.9
L.S.D.		12.9			18.0	

Yield Per Cent Cane (Table 20 in Appendix):

The quality (Y%C)* of the sound canes in this crop improved steadily up to the harvest at 18 months, and after dropping off in all treatments at 21 months, it made still further improvement by 27 months. (It must be remembered here that we discarded all dead and dying canes from the cane samples which we milled.)

Lbs. N applied	Average yield per cent cane at successive harvests: At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	6.7	9.0	9.8	10.5	12.3	12.3	9.7	11.5	13.6
40	7.7	9.9	10.3	—	—	—	—	—	—
100	6.3	9.1	9.6	9.8	11.5	12.5	11.0	12.0	13.1
160	5.4	8.6	9.9	10.1	11.4	12.7	11.2	12.2	13.8
220	4.4	7.6	9.1	9.6	11.4	12.4	11.3	12.4	13.8

Significant effects from the time of application of the nitrogen were found in the harvests at 15, 18, and 21 months, but they are quite different effects. At 15 months completion of the total nitrogen fertilization at four or six months (March or May) produced a better quality than when 60 pounds of the total were held back for an application at eleven months, although this was shown to be an effect from the lower amounts of nitrogen (100 and 160 pounds) which were used; it was not similarly found in the higher 220-pound N treatment. At 18 months the Y%C obtained when the total amounts were all applied by six

*Y%C = pounds of commercial sugar per 100 pounds of cane milled.

months (in May) was significantly higher than when the final applications were made at either four or eleven months. At 21 months the highest Y%C came from the treatments which received their final 60 pounds of N at eleven months in October.

Time of N application	Average yield per cent cane At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.
All N by 4th month	11.7	12.5	10.8	12.2
Last 60# at 6 mos.	11.8	13.1	11.1	12.1
Last 60# at 11 mos.	10.8	12.1	11.7	12.3
L.S.D.	0.8	0.5	0.4	ns

Yields of Reducing Sugars, Sucrose, Total Sugars, and Commercial Sugars (Tables 21, 22, 23, and 24 in Appendix):

Comparative yields from these four sugar measurements are shown in Fig. 18. Total sugars, sucrose, and commercial sugar reached their maximum at 18 months in May and then declined as the crop aged beyond this point. Sucrose made up slightly more than 90 per cent of the total sugars; commercial sugar yields were only about 80 per cent of the total sucrose.

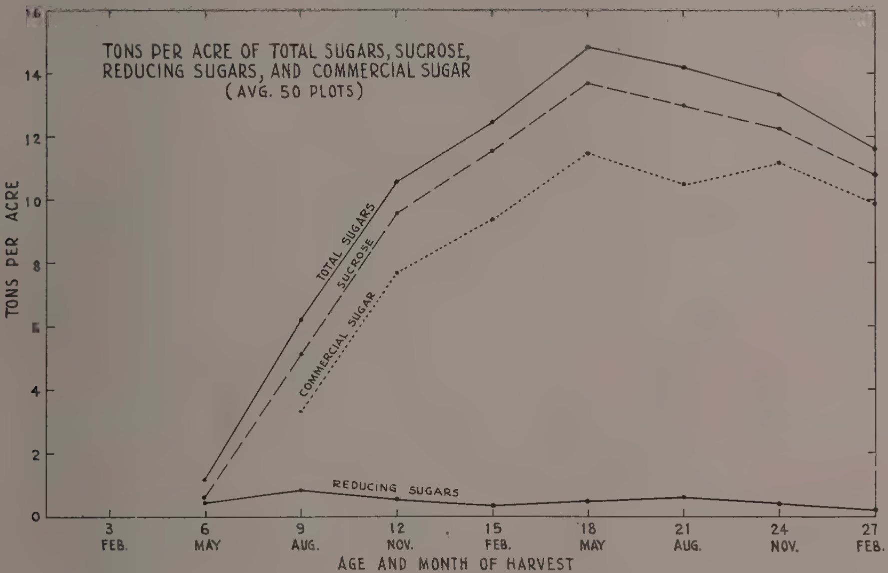


Fig. 18.

A pronounced drop in the amounts of recoverable or commercial sugar, which was not apparent in the sucrose or total sugars, occurred between 18 and 21 months.

This may have been due to the very slight increase in the amounts of reducing sugars which came at this time (perhaps from the increasing numbers of immature suckers in the cane samples milled), and also to a corresponding increase in the moisture content of the total green weight.

INCREASES OR LOSSES IN TOTAL TONS SUCROSE AND COMMERCIAL SUGAR PER ACRE

	3-6 mos.	6-9 mos.	9-12 mos.	12-15 mos.	15-18 mos.	18-21 mos.	21-24 mos.	24-27 mos.
Sucrose	+.61	+4.65	+4.40	+1.98	+2.16	− .70	− .72	−1.47
Comm. Sugar	—	+3.3	+4.4	+1.7	+2.1	−1.0	+0.7	−1.3

The different nitrogen applications had their specific effects on the yields of these different sugars, and each increase in amounts of nitrogen applied consistently raised them (see Table III).

TABLE III
AVERAGE YIELDS PER ACRE OF DIFFERENT SUGARS

Lbs. N applied	Tons/acre at 9 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar	Tons/acre at 10 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar
0	.23	1.98	2.32	1.4	.22	3.22	3.60	2.5
40	.32	3.91	4.44	2.7	.29	4.98	5.53	3.9
100	.67	5.10	6.05	3.6	.51	7.24	8.16	5.5
160	1.03	6.30	7.66	4.0	.78	8.85	10.09	6.6
220	1.44	6.27	8.05	3.5	1.16	9.10	10.74	6.6

Lbs. N applied	Tons/acre at 11 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar	Tons/acre at 12 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar
0	.23	3.94	4.37	3.2	.19	4.20	4.62	3.5
40	.27	5.77	6.34	4.4	—	—	—	—
100	.55	8.06	9.04	6.5	.50	8.39	9.32	6.8
160	.72	9.96	11.20	8.3	.59	10.59	11.74	8.6
220	.95	11.54	13.10	9.2	.70	11.48	12.77	9.2

Lbs. N applied	Tons/acre at 15 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar	Tons/acre at 18 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar
0	.15	4.95	5.36	4.2	.21	5.57	6.07	4.5
100	.30	9.88	10.70	8.1	.40	11.51	12.51	9.7
160	.35	12.37	13.38	10.0	.47	14.82	16.07	12.5
220	.43	14.56	15.76	12.0	.54	17.47	18.94	14.5

Lbs. N applied	Tons/acre at 21 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar	Tons/acre at 24 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar
0	.29	5.96	6.57	4.5	.27	6.06	6.66	5.9
100	.51	11.20	12.29	9.2	.40	10.86	11.84	9.9
160	.56	13.74	15.02	11.0	.44	13.04	14.17	11.8
220	.64	16.39	17.90	13.4	.50	15.02	16.34	13.8

Lbs. N applied	Tons/acre at 27 months: Red. Sugar	Sucrose	Total Sugars	Comm. Sugar
0	.12	5.38	5.79	5.0
100	.21	9.50	10.21	8.4
160	.22	10.95	11.71	10.3
220	.26	13.79	14.78	12.6

At many of the harvests the yields of these different sugars were also influenced by the time of applying the nitrogen fertilizer. Thus at nine, ten, and eleven months, the earlier (at four months) application produced more sugars than the later (at six months) applications. At twelve months the late eleven-month application was responsible for lower sugar yields than the two earlier "times". At 15 months there was a significantly higher yield of reducing sugars from the late N applications, and the sucrose, total and commercial sugars in the low-nitrogen treatments (A) were still lower than in those treatments which had received their total nitrogen application at four or six months; on the other hand

the late application for the high-nitrogen treatment (C) did not similarly affect its total and commercial sugar yields.

At 18 months only the tonnage of reducing sugars showed a significant "time of nitrogen" effect; this sugar was still higher when the final nitrogen was given at eleven months than when applied earlier. However, three months later when the crop was 21 months old, this situation apparently reversed itself, and after 21 months these yield differences were not significant effects from the time of application.

Time of N application	Tons/acre reducing sugars At 18 mos	At 21 mos.	At 24 mos.
All N by 4th month	.44	.62	.44
Last 60# at 6 months	.43	.59	.44
Last 60# at 11 months	.53	.50	.46
L.S.D.	.08	.09	ns

At 21 months an interaction between amounts and time influenced the yields of sucrose and of total and commercial sugars. This is nicely shown in the following three "two-way tables". Late applications of nitrogen were relatively ineffective when the total amount of nitrogen was only 100 pounds per acre, but when larger totals were supplied, there were some significant gains when part of the total was applied late.

Time of N application	Tons/ac. Sucrose — Amts. of N			Tons/ac. Total Sugar — Amts. of N			Tons/ac. Comm. Sugar — Amts. of N		
	100#	160#	220#	100#	160#	220#	100#	160#	220#
All N by 4th mo.	10.91	11.68	15.85	12.10	12.83	17.38	9.4	9.3	12.6
Last 60# at 6 mos.	12.14	14.00	15.09	13.30	15.33	16.53	9.9	11.2	12.0
Last 60# at 11 mos.	10.56	15.54	18.23	11.48	16.90	19.78	8.4	12.6	15.6
L.S.D.		2.56			2.72			2.1	

The highest average sugar yields in this experiment were obtained at 18, 24, and 21 months respectively. Averaging the yields secured at these three harvests and setting them up for ease of study in a "two-way table" to show the probable interaction between amounts and time, we have the following:

Time of N application	Average TSA for 3 harvests (18, 21, and 24 mos.) — Amounts of N applied 100#	160#	220#	Averages for Time of application
All N on by 4th mo.	9.9	10.6	13.9	11.5
Last 60# N at 6 mos.	9.7	12.5	12.7	11.6
Last 60# N at 11 mos.	9.2	12.3	15.1	12.2
Averages for Amts. of N	9.6	11.8	13.9	

Our interpretations from this table would be these: (1) The best sugar yield from this plant crop grown under the field conditions at Makiki came from the use of 220 pounds of N, especially when the last 60 pounds of this nitrogen was held off until the crop was eleven months old. (2) The next best yields came from 160 pounds of N per acre, and in this case a final 60 pounds at either six or eleven months was a better practice than completing the application at four months. (3) There was nothing gained by delaying the application of part of a total of only 100 pounds of nitrogen beyond four months.

The relative performance of the different treatments as measured in terms of sugar per acre per month may be seen in Table IV. The most outstanding features are (1) the excellence in some of these performances as early as eleven

and twelve months when Treatments B1, C1, and C2 reached their top levels of .8 TSAM, and (2) the manner in which all performances dropped at the harvests after 18 months. It is doubtful if there can be any better evidence presented to discourage long cropping of 32-8560 cane under growing conditions similar to those at Makiki.

TABLE IV

TONS SUGAR PER ACRE PER MONTH

Treatment	When harvested at 10 mos.	11 mos.	12 mos.	15 mos.	18 mos.	21 mos.	24 mos.	27 mos.
X	.25	.29	.29	.28	.25	.21	.25	.19
A1	.63	.65	.63	.73	.59	.45	.40	.30
A2	.47	.55	.59	.48	.55	.47	.41	.31
A3	.39*	.40*	.49	.41	.50	.40	.42	.32
B1	.70	.80	.80	.64	.69	.44	.42	.34
B2	.62	.69	.78	.73	.74	.53	.55	.40
B3	.63*	.65*	.58	.63	.65	.60	.50	.39
C1	.68	.80	.83	.79	.78	.60	.62	.43
C2	.63	.85	.78	.78	.79	.57	.50	.45
C3	.62*	.69*	.70	.82	.84	.74	.60	.52
Average	.56	.64	.64	.63	.64	.50	.47	.37

*Until after the harvest at eleven months, Treatment A3 had only received a total of 40 pounds of N; B3 only a total of 100 pounds N; and C3 only 160 pounds N.

Nitrogen Uptake

Pounds of Nitrogen Recovered (Table 25 in Appendix):

Recovery of nitrogen in the total dry weight was positively related to the amounts supplied by the fertilizer (Fig. 19). The "X" plots had picked up about 40 pounds per acre from the natural soil supplies within six months; this

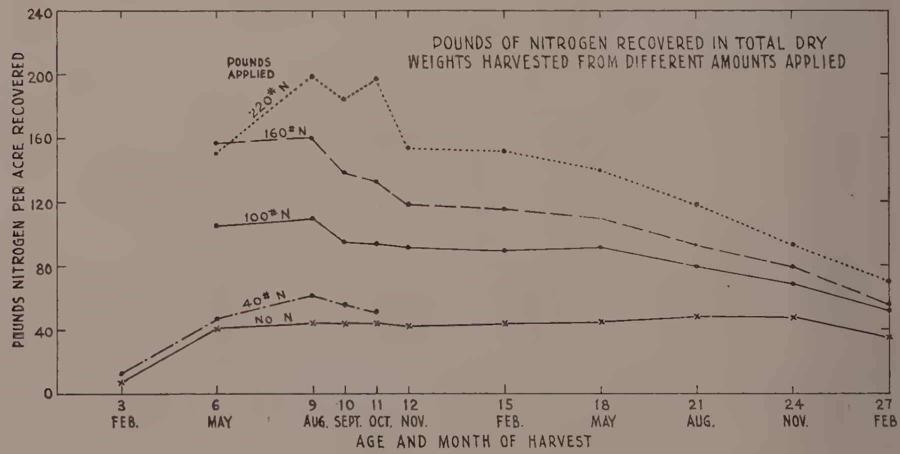


Fig. 19.

was only about one-third of the amount of nitrogen we had estimated to be available from this source.

Maximum amounts actually recovered were from the harvest at nine months;

after this the recovery figures drop because they do not include the nitrogen content in the trash blanket. Deducting the amount found in Treatment X from the amounts recovered from the crop which did get nitrogen fertilizer, we find that at the age of nine months, there were nitrogen recoveries in the above-ground dry weight of 44 per cent of the 40 pounds N application, of 65 per cent of the 100 pounds applied, of 72 per cent of the 160 pounds, and of 70 per cent of the 220-pound application. Undoubtedly much of the unrecovered nitrogen was in the roots and stubble which are not included in our data.

Some Interesting Ratios

(1) RATIO OF PER CENT TOTAL SUGARS TO PER CENT N IN TOTAL DRY WEIGHT

Lbs. N applied	Per cent total sugars ÷ per cent nitrogen At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.
40	36.0	142.7	196.1	240.9
100	24.4	105.4	168.1	189.2
160	18.7	94.9	144.9	166.9
220	15.3	80.0	115.5	131.0
Average	23.8	105.8	156.2	182.0

These ratios of total sugars to nitrogen increased with age, and decreased with each additional increment of nitrogen. The ratio of 167 to 1 (and higher) found at eleven months in the 160 pounds N treatment is apparently too high at this age, since an additional 60-pound nitrogen application eventually produced higher sugar yields.

(2) RATIO OF POUNDS N RECOVERED TO POUNDS N APPLIED

Available nitrogen From soil		Applied in fertilizer	Lbs. N recovered ÷ lbs. N applied At 6 mos.	At 9 mos.	At 12 mos.	At 15 mos	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
?	+	40	1.20	1.57	—	—	—	—	—	—
?	+	100	1.06	1.10	.94	.90	.92	.80	.69	.52
?	+	160	.99	1.00	.75	.73	.69	.58	.50	.35
?	+	220	.68	.91	.71	.69	.64	.54	.43	.32

The high ratios at six and nine months were due to the supply of available soil nitrogen. The decrease in ratios with the increases in age at harvest is most likely because much of the nitrogen was contained in the dead leaves and below-ground parts of the crop which were not recovered for weighing and analyses.

The higher ratios from the less liberally fertilized crops may indicate that such crops drew more heavily on the soil's nitrogen supply, in which case we could expect a greater depletion of this source of nitrogen; or it could indicate that there was an actual loss of some of the nitrogen supplied in the heavier total applications. This latter condition is doubtful, however, since at the age of nine months (when the percentage recoveries were maximum) the percentage recovery of nitrogen applied (excluding an amount equal to that recovered in the "no N" crop) was higher from the two larger than from the two smaller total applications:

PERCENTAGE RECOVERY OF APPLIED NITROGEN ONLY

Age	From 40# N	From 100# N	From 160# N	From 220# N
9 mos.	44.0	64.6	72.2	70.2

(3) RATIO OF POUNDS OF N RECOVERED IN TOTAL DRY WEIGHT TO TONS OF MILLABLE CANE HARVESTED

		Pounds N recovered÷T.C.A.					
Treat-ment	Lbs. N applied	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
A	100	1.33	1.29	1.18	.96	.84	.80
B	160	1.39	1.33	1.13	.95	.83	.76
C	220	1.63	1.46	1.22	1.01	.84	.77

Less nitrogen per ton of millable cane harvested was removed from the field with each increase in age of crop harvested. These ratios from the larger nitrogen applications were slightly higher, more especially when the crops were young. So once more it is apparent that after twelve months only between one and one and a half pounds of nitrogen actually leaves the field in each ton of stalks which is milled.

An indication of the relative efficiency from the actual amounts of nitrogen fertilizer that were applied can be found from (a) the number of pounds of N per ton of cane harvested, and (b) the pounds of N per ton of sugar, e.g.:

		Age at harvest					
	Treatment	12 mos.	15 mos.	18 mos.	21 mos.	24 mos.	27 mos.
Lbs. N/TCA							
	A	1.42	1.43	1.28	1.19	1.22	1.55
	B	1.87	1.82	1.63	1.62	1.66	2.14
	C	2.30	2.11	1.89	1.86	1.98	2.40
Lbs. N/TSA							
	A	14.7	12.4	10.3	10.9	10.1	11.9
	B	18.6	16.0	12.8	14.6	13.6	15.5
	C	23.9	18.3	15.2	16.4	15.9	17.5

The highest N efficiency for TCA came from Treatment A at 21 months when a ton of cane was produced with only 1.19 pounds of applied N; for TSA, our Treatment A at 24 months made the most efficient use of N and produced a ton of sugar for each 10.1 pounds of nitrogen it received.

Treatment C (which produced our highest yield of sugar at 18 months) showed an efficiency at 18 months that is represented by 1.89 pounds of nitrogen per ton of cane and 15.2 pounds of nitrogen per ton of sugar. (These figures are slightly higher than 1.79 and 14.3 pounds of nitrogen which we found in the 1944 crop.)

(4) RATIO OF PER CENT REDUCING SUGARS TO PER CENT SUCROSE

	Per cent reducing sugars÷per cent sucrose									
Lbs. N applied	At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	.50	.12	.067	.059	.046	.031	.038	.049	.045	.023
40	.46	.08	.059	.027	—	—	—	—	—	—
100	.86	.14	.071	.069	.060	.031	.035	.045	.037	.022
160	1.18	.16	.088	.071	.056	.029	.032	.041	.035	.020
220	1.44	.23	.127	.083	.060	.030	.031	.040	.035	.020

During the first year the ratio of reducing sugars to sucrose in the total dry weight increased as the nitrogen applications were increased, but this nitrogen effect disappeared as the drop matured. Full maturity of the primary stalks was apparent as this ratio declined and reached its low points at 15 months. Slight increases after 15 months were undoubtedly the effects from immature suckers, but the very low ratios at 27 months indicated their maturity by this time also.

(5) RATIO OF TONS TOTAL SUGARS TO TONS TOTAL DRY WEIGHT

Lbs. N applied	Tons Total Sugars÷tons total dry weight At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	.10	.31	.36	.37	.41	.45	.44	.41	.41	.46
40	.19	.35	.39	.43	—	—	—	—	—	—
100	.19	.34	.39	.40	.41	.46	.45	.44	.45	.48
160	.19	.34	.39	.40	.42	.46	.47	.46	.45	.48
220	.18	.34	.38	.39	.41	.46	.47	.46	.46	.49
Averages	.17	.34	.38	.40	.41	.46	.46	.44	.44	.48

Once more there were negligible differences in these ratios which can be the effect of the amounts of nitrogen applied. The ratios increased rapidly from six to nine months and thereafter more slowly. The higher ratios during the second year could be due to the nòn-inclusion of a substantial amount of dry weight in trash and its negligible amount of total sugars. Thus it is again most likely that the true ratio of sugars to total dry weight was quite constant at about .40 after the crop was ten or twelve months old.

(6) RATIO OF TONS REDUCING SUGARS TO TONS TOTAL DRY WEIGHT

Lbs. N applied	Tons reducing sugars÷tons total dry weight At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	.050	.031	.022	.020	.017	.013	.015	.018	017	.009
40	.059	.025	.021	.018	—	—	—	—	—	—
100	.084	.038	.024	.024	.022	.013	.015	.018	.015	.010
160	.100	.046	.030	.025	.021	.012	.014	.017	.014	.009
220	.102	.060	.041	.028	.022	.013	.013	.016	.014	.009

A definite influence of amounts of nitrogen applied was measured on this ratio of reducing sugars to total dry weight during the first year's growth; thereafter this same influence was not significant. The crop age effects decreased these ratios through the first 15 months; the slight increases thereafter were most likely due to the new additions in the stalk populations.

(7) RATIO OF TONS SUCROSE TO TONS TOTAL DRY WEIGHT

Lbs. N applied	Tons sucrose÷tons total dry weight At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	.10	.26	.32	.34	.37	.41	.40	.37	.38	.42
40	.13	.31	.35	.39	—	—	—	—	—	—
100	.10	.29	.34	.36	.37	.42	.42	.40	.41	.45
160	.09	.28	.34	.35	.38	.42	.43	.42	.42	.45
220	.07	.26	.32	.34	.37	.43	.43	.42	.42	.46

During the first ten or eleven months, increased nitrogen applications tended to give slightly lower ratios of sucrose to total dry weight, but in the second year's growth this trend seemed to have been reversed and the higher nitrogen applications then appeared to have given us slightly higher ratios.

(8) RATIO OF TONS SUCROSE TO TONS TOTAL SUGARS

Lbs. N applied	Tons sucrose÷tons total sugars At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	.65	.85	.89	.90	.91	.92	.92	.91	.91	.93
40	.66	.88	.90	.91	—	—	—	—	—	—
100	.52	.84	.89	.89	.90	.92	.92	.91	.92	.93
160	.45	.82	.88	.89	.90	.92	.92	.92	.92	.94
220	.40	.78	.85	.88	.90	.92	.92	.91	.92	.93

Nitrogen affected this ratio for only about ten or eleven months. After 15 months there was no further increase in the percentages of total sugars that were sucrose, and we note that this sucrose amounted to about 92 per cent of the total sugars in the total dry weight.

(9) RATIO OF TONS COMMERCIAL SUGAR TO TONS SUCROSE IN TOTAL DRY WEIGHT

Lbs. N applied	T.S.A. ÷ tons sucrose								
	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	.71	.78	.81	.83	.85	.81	.76	.97	.93
40	.69	.78	.76	—	—	—	—	—	—
100	.71	.76	.81	.81	.82	.84	.82	.91	.88
160	.63	.75	.83	.81	.81	.84	.80	.90	.94
220	.56	.73	.80	.80	.82	.83	.82	.92	.91
Average	.66	.76	.80	.81	.82	.83	.80	.92	.92

Nitrogen effects on this ratio did not persist for very long. An excellent recovery of the total sucrose in the commercial sugar was made as early as eleven months, and this ratio remained between .80 and .84 until the crop was 21 months old. At 24 and 27 months a rather spectacular increase of more than ten points occurred in the T.S.A. to sucrose ratio. It is difficult to assess the real causes for such an improvement in the commercial recovery of the sucrose, and we leave its explanation to the sugar technologists.

(10) RATIO OF MILLABLE CANE TO TOTAL GREEN WEIGHT HARVESTED

Lbs. N applied	T.C.A. ÷ tons total green weight									
	At 6 mos.	At 9 mos.	At 10 mos.	At 11 mos.	At 12 mos.	At 15 mos.	At 18 mos.	At 21 mos.	At 24 mos.	At 27 mos.
0	.40	.65	.74	.77	.80	.81	.78	.82	.87	.87
40	.49	.73	.77	.81	—	—	—	—	—	—
100	.53	.73	.77	.81	.84	.84	.84	.86	.89	.90
160	.54	.74	.78	.81	.84	.85	.86	.87	.90	.91
220	.51	.74	.78	.81	.83	.85	.86	.87	.91	.92
Averages	.49	.72	.77	.80	.83	.84	.84	.86	.89	.90

The different nitrogen treatments had no significant effects on these ratios of millable cane to total green weight. The gradual increases which went along with increased age of crop were undoubtedly due to the greatly shortened tops which were part of the total green weights at harvest. Since approximately 85 to 90 per cent of its total green weight of unburned cane was millable, it is apparent that such cane had a minimum tare of 10 to 15 per cent (for the green tops only which are included with cane milled).

Weather Relationship

Basic yield and weather data, tabulated for nine three-month periods, are given in Table V, and the relative utilization or efficiency of the sunlight and temperature by the 15 plots which received the high-nitrogen application (Treatment C) is given in Table VI.

The total green weight per unit of gram calories, sunshine, and day-degrees was higher during the second- and third-growth periods, while the cane was three

to nine months old, than at any more advanced age period. The best yields of total dry weight per unit of each weather measurement were obtained between six and nine months.

The efficiency of these three measurements on total dry weight was not significantly different during the second- and the sixth-growth periods, both of which occurred largely during the months of February, March, and April but in successive years.

Total sugars per unit of weather measurement were highest between six and nine months and declined thereafter. During the February-May period in the first year, the efficiency was considerable higher than during these same months in the second year when the crop was 15 to 18 months old.

In millable cane per unit of weather, the six-to-nine-month Period 3 again stood out above other growth periods. This third-period efficiency was 30 times that of the seventh period, although the same calendar months (May-August) were involved; there is little doubt that the crop-age effects were largely responsible.

All weather factors studied had their greatest influence on yields of commercial sugar during Period 4 (August to November) while the crop was nine to twelve months old; their efficiency was progressively lessened throughout the remaining growth periods.

TABLE V

BASIC YIELD AND WEATHER DATA

Growth Period	Dates	Age (mos.)	Increase in yield — tons/acre (Average of 15 plots of Treatment C) Grn. Wt.	Dry Wt.	Total Sugars	TCA	TSA
1	Nov. 8, 1944—Feb. 7, 1945	0–3	2.6	0.4	—	—	—
2	Feb. 8, 1945—May 9, 1945	3–6	43.1	6.7	1.33	24.8	—
3	May 10, 1945—Aug. 8, 1945	6–9	58.0	15.9	6.31	51.7	3.5
4	Aug. 9, 1945—Nov. 7, 1945	9–12	11.4	8.2	5.13	19.0	5.7
5	Nov. 8, 1945—Feb. 6, 1946	12–15	7.3	3.0	2.99	8.9	2.8
6	Feb. 7, 1946—May 8, 1946	15–18	12.8	6.2	3.18	12.0	2.5
7	May 9, 1946—Aug. 8, 1946	18–21	− 0.1	− 1.4	−1.04	+ 1.7	−1.1
8	Aug. 9, 1946—Nov. 6, 1946	21–24	−12.6	− 3.3	−1.56	− 7.0	+0.4
9	Nov. 7, 1946—Feb. 5, 1947	24–27	−23.5	− 5.8	−1.56	−19.6	−1.2

TABLE VI

SUNLIGHT AND TEMPERATURE UTILIZATION BY TREATMENT C (AVERAGE OF 15 PLOTS)

Growth period	Tons total Grn. Wt./acre Per 1000 gm. cal.	Per 100 hrs. sun	Per 1000 day-deg.	Tons total dry Wt./acre Per 1000 gm. cal.	Per 100 hrs. sun	Per 1000 day-deg.
1	.068	.367	2.793	.010	.056	.430
2	.927	6.122	42.505	.144	.952	6.607
3	1,012	6.808	41.311	.277	1.866	11.325
4	.228	1.429	8.000	.164	1.028	5.754
5	.230	1.311	7.337	.095	.539	3.015
6	.265	1.778	13.719	.128	.861	6.645
7	Loss	Loss	Loss	Loss	Loss	Loss
8	"	"	"	"	"	"
9	"	"	"	"	"	"

Growth period	Tons total sugars/acre Per 1000 gm. cal.	Per 100 hrs. sun	Per 1000 day-deg.	Tons millable cane/acre Per 1000 gm. cal.	Per 100 hrs. sun	Per 1000 day-deg.
1	—	—	—	—	—	—
2	.029	.189	1.312	.534	3.523	24.458
3	.110	.741	4.494	.902	6.068	36.823
4	.103	.643	3.600	.380	2.381	13.333
5	.094	.537	3.005	.280	1.598	8.945
6	.066	.442	3.408	.248	1.667	12.862
7	Loss	Loss	Loss	.030	.201	1.232
8	"	"	"	Loss	Loss	Loss
9	"	"	"	"	"	"

Growth period	Tons commercial sugar/acre Per 1000 gm. cal.	Per 100 hrs. sun	Per 1000 day-deg.
1	—	—	—
2	—	—	—
3	.061	.411	2.493
4	.114	.714	4.000
5	.088	.503	2.814
6	.052	.347	2.680
7	Loss	Loss	Loss
8	.008	.049	.288
9	Loss	Loss	Loss

Summary

The available soil nitrogen supply was at a high level while this crop was getting established, but during the second year its amount dropped and fluctuated considerably between 60 and 100 pounds per acre.

The character of the stalk population was affected by the nitrogen applications. The higher amounts produced a more dense stalk population, but were also responsible for a higher mortality of primaries and a greater incidence of suckers. Only one-half of the living primary stalks that were in the field at twelve months were still there at 24 months; only one-third of the sound primaries found at 18 months were living at 27 months.

The heavier amounts of nitrogen reduced the amount of tasseling, especially when applications were made early.

The higher nitrogen applications produced the heavier tonnages of green tops. Maximum tonnage of tops when the crop was nine months old again suggests this "boom stage" of growth as the time when maximum photosynthesis is possible.

Moisture content and reducing sugar concentration in the total dry weight were increased with increased applications of nitrogen, more especially in the first year's growth.

Lower concentration of sucrose in total dry weight resulted from increased nitrogen during the first year's growth, but this effect disappeared during the second year.

Total sugars in dry weight, which were more than 90 per cent sucrose, were found in higher concentration after 15 months in the more heavily nitrogen fertilized plots.

The concentration of nitrogen increased in all parts of the plant studied whenever the nitrogen fertilizer applications were increased; this response to nitrogen was quite rapid, i.e., within four weeks. Deficiency levels for nitrogen

were indicated for 32-8560 cane at eleven months of age as .230 per cent N in the total dry weight, 1.28 per cent N in the leaf-punch samples, .89 per cent N in the leaf blades, .011 per cent N in the crusher juices, and .0226 per cent amino nitrogen in the elongating cane. Additional applications of N were called for when these concentrations were below these levels when the crop had another year to grow before harvest.

The "primary index" again showed a positive relationship between total sugars and moisture in the leaf sheaths and the nitrogen in the leaf-punch samples. Furthermore, the best commercial sugar yields came from those canes which had the higher primary index values (per cent total sugars in leaf sheaths) at ten-eleven months.

Direct increases in the yields of total green weight, total dry weight, and millable cane were the result from each additional amount of nitrogen fertilizer applied. The crop made its most rapid development prior to nine months; at this age 63 per cent of its maximum yield of millable cane was "in the field". Several interesting interactions between amounts of nitrogen and its time of application were noted at 15 and 21 months.

Cane quality as a whole after twelve months did not show significant effects from the different amounts of nitrogen applied, but there were some Y%C differences which resulted when the final nitrogen application was delayed beyond six months.

In general, each increase in amounts of nitrogen applied increased the yield of total sugars, reducing sugars, sucrose, and commercial sugars. Maximum commercial sugar recovery came at 18 months; 67 per cent of this maximum was in the field at twelve months. An influence from time of application on effects from different amounts of nitrogen applied was found at 21 months; the late applications were relatively ineffective when the total amount was inadequate, but with larger totals, better yields occurred when a late application was made at eleven months.

Very creditable average sugar-per-acre-per-month values (.64 TSAM) were obtained as early as eleven months, and nothing was gained by postponing this harvest beyond 18 months.

Recovery of nitrogen in the total dry weight was positively related to the amounts of nitrogen applied.

A study of many of the ratios between the measurements that were made points out some very interesting relationships. For instance: the *increased* nitrogen applications (1) decreased the ratio of total sugars to nitrogen in the total dry weight; (2) resulted in a lower precentage of nitrogen being recovered in the total dry weight from the total pounds of nitrogen applied; (3) increased the amount of nitrogen found in each ton of millable cane, or recovered for each ton of commercial sugar made; (4) increased the ratio of per cent reducing sugars to sucrose during the first year's growth; (5) had little if any effect on the ratio of total sugars to total dry weight; (6) increased the percentage of total dry weight which was reducing sugars during the first year only; (7) gave slightly lower ratios of tons sucrose to tons total dry weight in the first year, but slightly higher ratios in the second year's growth; (8) reduced the ratio of tons sucrose to tons total sugars during the first ten or eleven months only; (9) had only a few months' effect on the commercial sugar — sucrose ratio; and (10) did not influence the

ratio of millable cane to total green weight harvested. Weather factors showed great differences in their effectiveness at different growth stages.

Acknowledgment

This report which is the fifth in a series of cooperative studies concerned with nitrogen investigations was made possible as a result of the fine cooperation of a large number of members of the staffs of the Chemistry department, of the Physiology and Biochemistry department, and of the Agriculture department who have assisted in growing the crops, taking the soil and crop samples, harvesting and preparing the crop samples for the numerous chemical analyses, and in making the statistical studies of the results which were reported. To all these people we are sincerely indebted.

APPENDIX

Containing Summaries of Data and Statistical Measurements from Makiki Experiment 22 ATN

Avg. = General average.
S.D. = Standard deviation.
C.V. = Coefficient of variation.
ns = Treatment effect not significant.
M.d.r.* = Minimum difference required for significance (for P at .05 or odds of 19 to 1).

At the first harvest, a minimum difference between the average of the five "X" plots and the average of the 45 plots which had received 40 pounds of nitrogen would be .94×S.D.

At the second harvest at six months, one may calculate the M.d.r.'s as follows:

For comparing the averages of X and C1: M.d.r. = 1.27×S.D.

For comparing X or C1 with either B1 or A2: M.d.r. = 1.11×S.D.

For comparing X or C1 with A1: M.d.r. = 1.01×S.D.

For comparing B1 or A2 with A1: M.d.r. = .79×S.D.

At the third, fourth, and fifth harvests, these M.d.r.'s would be:

For comparing any two averages from Treatments X, B1, C1, A2, C2, or A2: M.d.r. = 1.29×S.D.

For comparing averages from X, or B1, or C1, or A2, or C2, or A3 with either A1 or B2: M.d.r. = 1.12×S.D.

For comparing A1 with B2: M.d.r. = .92×S.D.

At all later harvests the M.d.r. between averages of any two treatments would be 1.28×S.D.

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*Note: The M.d.r. between any two specific treatment averages at the first five harvests has been calculated from the formula:

$$t \times S.D. \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

TABLE I

PER CENT TOPS IN TOTAL GREEN WEIGHT

Treat-ments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	100	60.21	32.18	26.49	23.74	20.01	19.15	21.56	18.23	13.12	13.00
A1	5	100	47.42	25.73	22.32	18.71	15.20	13.39	14.79	12.31	10.57	10.65
B1	5	See A1	46.54	24.64	21.38	18.76	15.76	12.63	12.41	12.43	9.54	9.67
C1	5	"	48.89	26.28	22.03	18.68	16.88	14.69	14.28	14.28	9.94	8.53
A2	5	"	52.37	29.27	24.57	20.50	16.09	14.14	15.97	14.38	11.27	9.60
B2	5	"	See A1	26.87	22.31	19.27	16.58	14.23	13.94	13.24	11.01	9.38
C2	5	"	See B1	26.47	22.05	20.22	17.46	13.85	13.50	11.58	10.44	7.62
A3	5	"	See A2	27.48	23.26	18.88	17.10	21.20	18.34	15.39	10.29	8.32
B3	5	"	See A1	See A1	See A1	See A1	17.32	16.92	15.44	13.98	10.67	7.03
C3	5	"	See A1	See B2	See B2	See B2	16.83	15.47	14.01	12.12	9.14	6.98
Avg.	50	100	49.66	27.37	23.05	19.85	16.92	15.57	15.42	13.79	10.60	9.08
S.D.		—	3.97	1.75	1.11	1.24	1.42	1.21	1.65	2.02	1.20	1.33
C.V.		—	8.0	6.4	4.8	6.2	8.4	7.8	10.7	14.6	11.3	14.6
M.d.r.		—	*	*	*	*	1.83	1.56	2.11	2.60	1.54	1.71

TABLE 2

PER CENT MOISTURE IN TOTAL GREEN WEIGHT

Treat-ments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	82.35	81.10	75.91	73.03	72.48	72.58	71.50	70.78	71.33	72.61	70.14
A1	5	83.57	83.73	75.76	72.65	72.93	73.51	70.75	69.86	72.62	71.87	70.66
B1	5	See A1	84.86	77.01	72.84	72.51	72.33	71.44	69.76	71.83	71.37	70.26
C1	5	"	84.71	77.86	74.47	73.48	72.45	71.62	69.71	71.61	70.98	70.18
A2	5	"	81.08	77.76	73.92	73.51	73.46	71.38	69.83	71.31	70.92	70.64
B2	5	"	See A1	77.42	73.90	72.89	72.98	71.06	69.78	70.80	71.15	70.52
C2	5	"	See B1	77.86	73.60	72.63	72.83	71.81	69.84	71.29	71.42	70.27
A3	5	"	See A2	74.55	72.54	72.06	72.71	73.91	71.29	70.35	71.11	69.99
B3	5	"	See A1	See A1	See A1	See A1	72.50	72.41	70.44	70.74	70.90	69.98
C3	5	"	See A1	See B2	See B2	See B2	73.40	72.74	70.68	70.72	70.55	69.33
Avg.	50	83.45	83.26	76.77	73.37	72.81	72.88	71.86	70.20	71.26	71.29	70.20
S.D.		.51	.75	.71	.91	.87	1.46	1.06	1.04	1.04	1.07	.77
C.V.		0.6	0.9	0.9	1.2	1.2	2.0	1.5	1.5	1.5	1.5	1.1
M.d.r.		.48	*	*	*	*	ns	1.36	ns	ns	1.38	ns

TABLE 3

PER CENT MOISTURE IN LEAF SHEATHS

Treat-ments	No. of plots	Age and month of harvest 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	80.39	78.71	77.37	77.10	75.41	76.02	72.77	72.90	75.90	76.51
A1	5	—	83.01	78.65	76.74	77.17	76.63	76.34	72.14	73.35	74.49	74.70
B1	5	—	84.02	80.65	77.61	77.10	76.39	78.08	73.07	73.39	74.43	73.65
C1	5	—	84.24	80.67	78.81	78.97	77.62	76.84	73.02	74.38	74.12	74.84
A2	5	—	80.56	80.33	77.24	77.31	77.42	77.31	73.14	73.45	74.63	74.60
B2	5	—	See A1	80.55	78.35	78.05	76.99	76.43	72.68	73.12	73.47	74.82
C2	5	—	See B1	80.90	78.12	77.29	77.39	77.53	73.40	73.26	75.02	74.45
A3	5	—	See A2	77.81	76.32	76.24	76.12	78.09	73.77	74.70	75.68	75.06
B3	5	—	See A1	See A1	See A1	See A1	76.78	77.23	72.83	73.21	74.69	74.64
C3	5	—	See A1	See B2	See B2	See B2	77.38	78.17	73.47	74.00	74.54	73.97
Avg.	50	—	82.58	79.78	77.57	77.40	76.81	77.21	73.03	73.58	74.70	74.72
S.D.		—	.71	.94	.88	.81	1.34	1.29	1.18	1.35	1.15	1.39
C.V.		—	0.9	1.2	1.1	1.0	1.7	1.7	1.6	1.8	1.5	1.9
M.d.r.		—	*	*	*	*	1.73	ns	ns	ns	1.48	1.79

TABLE 4

PER CENT MOISTURE IN LEAF BLADES

Treat-ments	No. of plots	Age and month of harvest 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	71.01	66.78	65.17	64.47	63.54	64.45	61.63	60.02	61.73	64.62
A1	5	—	74.19	66.50	64.80	65.06	64.44	64.46	62.02	61.48	62.86	64.64
B1	5	—	74.88	68.55	66.34	65.34	64.36	67.65	62.81	61.96	62.79	64.50
C1	5	—	75.08	68.46	66.20	66.11	65.44	66.61	63.58	62.00	62.71	65.49
A2	5	—	71.56	68.47	65.69	65.13	64.58	66.22	63.74	59.87	63.16	64.63
B2	5	—	See A1	68.35	65.79	65.56	64.32	66.13	63.23	60.19	61.19	64.42
C2	5	—	See B1	68.71	66.19	65.45	64.30	66.65	63.30	60.40	62.92	64.42
A3	5	—	See A2	65.69	64.52	63.67	64.55	66.17	62.89	61.99	63.14	64.56
B3	5	—	See A1	See A1	See A1	See A1	63.84	66.59	62.14	60.74	62.81	64.07
C3	5	—	See A1	See B2	See B2	See B2	64.36	66.34	62.65	61.79	63.24	63.48
Avg.	50	—	73.57	67.69	65.59	65.10	64.37	66.13	62.80	61.04	62.66	64.48
S.D.		—	.93	.60	.79	.98	1.58	1.48	1.30	1.54	1.46	1.32
C.V.		—	1.3	0.9	1.2	1.5	2.5	2.2	2.1	2.5	2.3	2.0
M.d.r.		—	*	*	*	*	ns	1.91	ns	ns	ns	ns

TABLE 5

PER CENT REDUCING SUGARS IN TOTAL DRY WEIGHT

Treat-ments	No. of plots	3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
		Age and month of harvest										
X	5	—	5.060	3.057	2.129	1.997	1.699	1.285	1.532	1.823	1.690	.959
A1	5	—	8.393	3.506	2.344	2.319	2.386	1.057	1.357	2.331	1.651	1.123
B1	5	—	10.024	4.655	2.943	2.677	2.332	1.049	1.187	1.893	1.588	.937
C1	5	—	10.075	6.171	4.320	3.084	2.210	1.161	1.277	1.899	1.324	.982
A2	5	—	5.678	4.170	2.504	2.568	2.539	1.019	1.230	1.706	1.298	.956
B2	5	—	See A1	4.396	3.002	2.348	2.045	1.166	1.340	1.811	1.407	1.006
C2	5	—	See B1	5.823	3.769	2.558	2.243	1.283	1.300	1.824	1.676	.884
A3	5	—	See A2	2.524	2.071	1.777	1.827	1.891	1.670	1.396	1.586	.907
B3	5	—	See A1	See A1	See A1	See A1	1.937	1.413	1.588	1.491	1.341	.828
C3	5	—	See A1	See B2	See B2	See B2	2.231	1.382	1.436	1.358	1.408	.857
Avg.	50	—	8.011	4.288	2.885	2.416	2.145	1.271	1.392	1.753	1.497	.944
S.D.		—	1.200	.970	.728	.412	.529	.283	.245	.412	.357	.159
C.V.		—	18.0	22.6	25.2	17.1	24.7	22.3	17.6	23.8	23.8	16.8
M.d.r.		—	*	*	*	*	ns	.363	.315	.536	ns	ns

TABLE 6

PER CENT REDUCING SUGARS IN ELONGATING CANE

Treat-ments	No. of plots	3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
		Age and month of harvest										
X	5	—	1.93	1.13	1.22	1.80	1.13	.74	.78	1.32	1.08	1.11
A1	5	—	2.23	1.23	1.48	1.92	1.30	.86	.81	1.34	1.07	.86
B1	5	—	2.15	1.28	1.58	1.99	1.44	.92	.88	1.40	1.28	.93
C1	5	—	2.19	1.36	1.65	1.92	1.48	1.19	.76	1.62	1.06	.99
A2	5	—	2.09	1.22	1.40	1.76	1.53	1.04	1.11	1.57	1.22	1.03
B2	5	—	See A1	1.22	1.40	1.90	1.46	.89	.88	1.50	1.12	.79
C2	5	—	See B1	1.32	1.71	1.85	1.29	.87	1.12	1.58	1.40	.98
A3	5	—	See A2	1.21	1.34	1.62	1.18	.56	1.02	1.56	1.25	.84
B3	5	—	See A1	See A1	See A1	See A1	1.47	.62	1.14	1.48	1.16	.83
C3	5	—	See A1	See B2	See B2	See B2	1.64	.85	.97	1.58	1.15	.76
Avg.	50	—	2.15	1.25	1.47	1.84	1.39	.85	.95	1.50	1.18	.91
S.D.		—	.32	.16	.20	.21	.24	.24	.27	.28	.22	.34
C.V.		—	14.9	12.8	13.6	11.4	17.3	28.2	28.4	18.7	18.6	37.4
M.d.r.		—	*	ns	*	ns	.31	.30	.35	ns	ns	ns

TABLE 7

PER CENT SUCROSE IN TOTAL DRY WEIGHT

Treat-ments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	10.201	26.189	31.910	33.691	36.538	41.252	40.421	37.058	37.444	42.516
A1	5	—	9.729	30.578	35.159	36.757	37.329	43.919	42.764	40.384	41.472	44.777
B1	5	—	8.504	28.570	34.301	35.147	37.430	43.617	44.736	41.364	41.555	44.959
C1	5	—	7.008	25.978	31.237	33.740	36.273	43.019	42.807	41.547	42.177	46.828
A2	5	—	12.475	26.196	33.499	34.436	36.373	43.616	43.340	40.170	42.371	45.167
B2	5	—	See A1	26.999	33.286	35.247	37.994	43.141	44.112	41.630	40.901	44.315
C2	5	—	See B1	26.194	32.401	34.330	37.118	42.959	44.127	42.494	42.020	47.376
A3	5	—	See A2	30.967	35.344	38.807	38.378	38.378	39.304	40.700	39.472	44.971
B3	5	—	See A1	See A1	See A1	See A1	38.081	40.353	41.282	42.427	42.878	46.020
C3	5	—	See A1	See B2	See B2	See B2	37.271	41.759	42.848	42.096	41.709	44.663
Avg.	50	—	9.808	27.709	33.392	35.269	37.279	42.201	42.574	40.987	41.200	45.159
S.D.		—	1.170	1.738	1.221	1.356	1.292	1.643	1.493	1.634	1.957	1.667
C.V.		—	11.9	6.3	3.8	3.4	3.5	3.9	3.5	4.0	4.8	3.7
M.d.r.		—	*	*	*	*	ns	2.113	1.916	2.099	2.511	2.140

TABLE 8

PER CENT SUCROSE IN ELONGATING CANE

Treat-ments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	1.04	.70	1.03	.62	.87	3.15	1.91	2.18	2.10	1.94
A1	5	—	.66	.75	.98	.61	.81	2.49	2.21	2.16	2.32	2.30
B1	5	—	.69	.50	.97	.62	.83	2.06	1.86	2.51	2.31	2.56
C1	5	—	.77	.55	.78	.45	.72	2.17	1.81	1.72	1.97	2.10
A2	5	—	.75	.50	.96	.65	.63	2.47	1.84	2.10	2.31	2.31
B2	5	—	See A1	.54	.96	.62	.60	2.48	1.93	1.92	2.26	2.57
C2	5	—	See B1	.58	.99	.63	.77	2.17	1.47	1.89	1.66	2.89
A3	5	—	See A2	.77	1.05	.82	.73	2.54	1.80	2.07	2.08	2.59
B3	5	—	See A1	See A1	See A1	See A1	.61	3.36	1.76	2.00	2.02	2.70
C3	5	—	See A1	See B2	See B2	See B2	.71	2.45	1.78	1.75	2.02	2.69
Avg.	50	—	.73	.61	.97	.63	.73	2.53	1.84	2.03	2.10	2.46
S.D.		—	.36	.15	.18	.18	.25	.91	.36	.53	.67	.91
C.V.		—	49.3	24.6	18.6	28.6	34.2	36.0	19.6	26.1	31.9	37.0
M.d.r.		—	ns	*	ns	ns	ns	ns	ns	ns	ns	ns

TABLE 9

PER CENT TOTAL SUGARS IN TOTAL DRY WEIGHT

Treatments	No. of plots	Age and month of harvest: 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	15.798	30.630	35.708	37.461	40.165	44.709	44.081	40.831	41.105	45.695
A1	5	—	18.635	35.693	39.364	41.010	41.680	47.286	46.382	44.841	45.306	48.257
B1	5	—	18.977	34.728	39.025	39.673	41.733	46.961	48.278	45.434	45.331	47.863
C1	5	—	17.458	33.517	37.201	38.600	40.393	46.445	46.337	45.632	45.922	50.274
A2	5	—	18.811	31.746	37.967	38.826	40.715	46.929	46.829	43.970	45.899	48.501
B2	5	—	See A1	32.815	38.039	39.451	42.039	46.581	47.775	45.635	44.461	47.653
C2	5	—	See B1	33 395	37.875	38.698	41.163	46.503	47.770	46.555	45.908	50.754
A3	5	—	See A2	35.112	39.212	42.637	42.236	42.290	43.040	44.228	43.137	48.246
B3	5	—	See A1	See A1	See A1	See A1	42.015	43.892	45.041	46.152	46.475	49.264
C3	5	—	See A1	See B2	See B2	See B2	41.463	45.339	46.540	45.670	45.304	47.870
Avg.	50	—	18.337	33.455	38.049	39.544	41.360	45.694	46.207	44.895	44.885	48.438
S.D.		—	1.744	1.720	1.264	1.300	1.212	1.643	1.526	1.597	1.863	1.811
C.V.		—	9.5	5.1	3.3	3.3	2.9	3.6	3.3	3.6	4.2	3.7
M.d.r.		—	*	*	*	*	1.557	2.109	1.959	2.050	2.393	2.324

TABLE 10

PER CENT TOTAL SUGARS IN ELONGATING CANE

Treatments	No. of plots	Age and month of harvest: 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	2.96	1.84	2.25	2.42	2.00	3.89	2.69	3.50	3.18	3.05
A1	5	—	2.89	1.98	2.46	2.53	2.10	3.35	3.01	3.50	3.38	3.16
B1	5	—	2.83	1.78	2.55	2.61	2.26	2.98	2.74	3.91	3.59	3.49
C1	5	—	2.96	1.91	2.43	2.36	2.20	3.36	2.58	3.34	3.03	3.09
A2	5	—	2.84	1.72	2.36	2.41	2.16	3.51	2.95	3.67	3.52	3.34
B2	5	—	See A1	1.76	2.36	2.52	2.06	3.37	2.81	3.42	3.37	3.36
C2	5	—	See B1	1.90	2.70	2.48	2.05	3.04	2.59	3.47	3.06	3.87
A3	5	—	See A2	1.98	2.38	2.44	1.91	3.10	2.82	3.63	3.33	3.43
B3	5	—	See A1	See A1	See A1	See A1	2.07	3.98	2.90	3.48	3.18	3.53
C3	5	—	See A1	See B2	See B2	See B2	2.35	3.29	2.75	3.33	3.17	3.47
Avg.	50	—	2.88	1.86	2.44	2.47	2.12	3.39	2.78	3.53	3.28	3.37
S.D.		—	.32	.20	.21	.20	.29	.88	.26	.39	.63	.74
C.V.		—	11.1	10.8	8.6	8.1	13.7	26.0	9.4	11.0	19.2	22.0
M.d.r.		—	*	ns	*	ns	ns	ns	.32	ns	ns	ns

TABLE 11

PER CENT TOTAL SUGARS IN LEAF SHEATHS

Treatments	No. of plots	Age and month of harvest 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	11.199	8.727	9.462	7.916	8.032	8.467	12.936	12.145	9.109	13.999
A1	5	—	11.018	8.347	10.520	8.616	9.021	9.122	13.500	11.610	9.736	14.664
B1	5	—	12.353	8.098	11.595	9.883	9.828	8.765	12.562	11.733	9.932	15.396
C1	5	—	13.724	9.711	11.928	9.274	9.397	8.841	13.203	10.784	9.176	14.953
A2	5	—	10.637	8.376	10.241	8.412	9.382	8.974	12.725	11.272	10.305	16 527
B2	5	—	See A1	8.543	11.339	8.987	8.570	9.199	13.505	12.016	9.391	14.258
C2	5	—	See B1	9.605	13.257	10.818	9.493	9.068	12.757	11.278	9.949	16.282
A3	5	—	See A2	8.845	9.406	8.281	7.877	7.947	12.099	10.635	8.853	15.272
B3	5	—	See A1	See A1	See A1	See A1	8.368	9.178	12.555	11.720	9.610	14.897
C3	5	—	See A1	See B2	See B2	See B2	9.603	8.564	12.260	10.904	10.038	15.837
Avg.	50	—	11.497	8.781	10.969	9.023	8.957	8.812	12.810	11.410	9.610	15.208
S.D.		—	1.296	.989	.916	.995	.742	.819	1.153	.949	1.503	1.800
C.V.		—	11.3	11.3	8.4	11.0	8.3	9.3	9.0	8.3	15.6	11.8
M.d.r.		—	*	*	*	*	.960	ns	ns	1.218	ns	ns

TABLE 12

PER CENT NITROGEN IN TOTAL DRY WEIGHT

Treatments	No. of plots	Age and month of harvest 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	1.320	.576	.297	.224	.197	.184	.192	.167	.156	.152	.139
A1	5	1.575	.766	.276	.218	.198	.204	.160	.140	.143	.136	.131
B1	5	See A1	1.015	.354	.266	.244	.218	.188	.154	.147	.135	.116
C1	5	"	1.141	.399	.319	.301	.247	.222	.171	.157	.132	.117
A2	5	"	.522	.365	.243	.223	.206	.180	.163	.141	.127	.123
B2	5	"	See A1	.358	.267	.230	.202	.188	.156	.138	.134	.124
C2	5	"	See B1	.437	.330	.289	.256	.222	.170	.155	.136	.123
A3	5	"	See A2	.246	.200	.177	.226	.256	.196	.151	.129	.115
B3	5	"	See A1	See A1	See A1	See A1	.228	.226	.176	.140	.118	.110
C3	5	"	See A1	See B2	See B2	See B2	.249	.228	.184	.149	.131	.117
Avg.	50	1.551	.786	.337	.255	.232	.222	.206	.168	.148	.133	.122
S.D.		.094	.049	.043	.024	.016	.023	.020	.017	.013	.012	.013
C.V.		5.8	6.3	11.7	7.7	6.9	10.4	9.5	10.1	8.8	9.0	10.7
M.d.r.		—	*	*	*	*	.029	.026	.022	.017	.015	.017

TABLE 13

PER CENT NITROGEN IN LEAF-PUNCH SAMPLES FROM BLADES

Treat-ments	No. of plots	Age and month of harvest: 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	1.91	1.41	1.20	1.08	1.16	1.30	1.17	1.03	.92	.96	1.14
A1	5	2.35	1.80	1.34	1.12	1.19	1.41	1.21	.93	.96	.93	1.06
B1	5	See A1	2.08	1.48	1.23	1.24	1.38	1.34	.98	.94	.93	1.04
C1	5	"	2.17	1.56	1.32	1.35	1.46	1.27	1.02	1.00	.94	1.04
A2	5	"	1.46	1.42	1.16	1.21	1.36	1.22	1.03	1.00	.95	1.06
B2	5	"	See A1	1.49	1.27	1.28	1.40	1.18	.98	.93	.93	1.08
C2	5	"	See B1	1.56	1.32	1.33	1.44	1.30	1.00	.98	.97	1.02
A3	5	"	See A2	1.27	1.06	1.08	1.48	1.35	1.02	.98	.93	1.03
B3	5	"	See A1	See A1	See A1	See A1	1.50	1.35	.98	.94	.96	1.02
C3	5	"	See A1	See B2	See B2	See B2	1.54	1.35	1.03	.96	.89	.97
Avg.	50	2.31	1.79	1.42	1.20	1.23	1.43	1.27	1.00	.96	.94	1.05
S.D.		.07	.06	.04	.07	.06	.07	.08	.09	.05	.08	.07
C.V.		3.0	3.4	2.8	5.8	4.9	4.9	6.3	9.0	5.2	8.5	6.7
M.d.r.		.07	*	*	*	*	.09	.10	ns	.06	ns	.09

TABLE 14

PER CENT NITROGEN IN LEAF BLADES (ENTIRE)

Treat-ments	No. of plots	Age and month of harvest: 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	1.01	.82	.87	.80	.95	.84	.70	.64	.74	.83
A1	5	—	1.34	.87	.90	.81	1.09	.84	.64	.66	.68	.82
B1	5	—	1.54	1.01	.94	.91	1.06	.97	.69	.64	.67	.75
C1	5	—	1.64	1.06	1.02	.96	1.08	.90	.73	.70	.70	.77
A2	5	—	1.02	.99	.92	.86	1.05	.90	.71	.68	.71	.79
B2	5	—	See A1	1.03	.96	.89	1.02	.85	.66	.64	.68	.81
C2	5	—	See B1	1.07	.99	.97	1.07	.93	.69	.68	.72	.71
A3	5	—	See A2	.82	.83	.78	1.17	1.01	.70	.67	.70	.78
B3	5	—	See A1	See A1	See A1	See A1	1.15	.98	.67	.65	.71	.77
C3	5	—	See A1	See B2	See B2	See B2	1.16	1.03	.70	.65	.65	.75
Avg.	50	—	1.31	.96	.93	.87	1.08	.93	.69	.66	.70	.78
S.D.		—	.05	.04	.05	.04	.08	.08	.05	.05	.06	.09
C.V.		—	3.8	4.2	5.4	4.6	7.4	8.6	7.2	7.6	8.6	11.5
M.d.r.		—	*	*	*	*	.10	.10	ns	ns	ns	ns

TABLE 15

PER CENT NITROGEN IN CRUSHER JUICES

Treatments	No. of plots	Age and month of harvest 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	.022	.009	.008	.009	.008	.010	.008	.007	.010	.010
A1	5	—	.027	.010	.009	.009	.012	.009	.008	.008	.010	.011
B1	5	—	.050	.015	.014	.014	.013	.014	.012	.008	.010	.010
C1	5	—	.064	.018	.016	.017	.016	.018	.014	.012	.011	.012
A2	5	—	.019	.012	.009	.009	.010	.011	.010	.008	.009	.011
B2	5	—	See A1	.013	.012	.011	.011	.016	.011	.009	.010	.011
C2	5	—	See B1	.018	.017	.016	.016	.016	.014	.010	.011	.012
A3	5	—	See A2	.008	.007	.007	.012	.013	.011	.009	.010	.011
B3	5	—	See A1	See A1	See A1	See A1	.012	.014	.011	.009	.010	.010
C3	5	—	See A1	See B2	See B2	See B2	.013	.016	.012	.011	.010	.011
Avg.	50	—	.033	.013	.011	.011	.012	.014	.011	.009	.010	.011
S.D.		—	.005	.002	.001	.001	.002	.003	.001	.002	.001	.001
C.V.		—	15.2	15.4	9.1	9.1	16.7	21.4	9.1	22.2	10.0	9.1
M.d.r.		—	*	*	*	*	.005	.004	.002	.002	.001	.001

TABLE 16

P.P.M. AMINO NITROGEN IN ELONGATING CANE

Treatments	No. of plots	Age and month of harvest 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	131	123	149	165	172	154	156	122	180	151
A1	5	—	197	177	182	200	238	176	184	122	172	162
B1	5	—	262	189	211	213	219	207	195	141	199	160
C1	5	—	298	213	236	236	231	221	194	134	186	169
A2	5	—	152	193	198	201	209	165	179	116	181	150
B2	5	—	See A1	189	223	226	241	189	196	145	189	150
C2	5	—	See B1	211	211	219	230	197	184	153	188	156
A3	5	—	See A2	176	173	183	233	212	170	132	170	149
B3	5	—	See A1	See A1	See A1	See A1	244	212	204	138	207	151
C3	5	—	See A1	See B2	See B2	See B2	256	205	208	147	188	163
Avg.	50	—	205	184	198	205	227	194	187	135	186	156
S.D.		—	30	16	25	21	27	33	26	25	30	24
C.V.		—	14.6	8.7	12.6	10.2	11.9	17.0	13.9	18.5	16.1	15.4
M.d.r.		—	*	*	*	*	35	43	32	ns	ns	ns

TABLE 17

TOTAL GREEN WEIGHT — TONS PER ACRE

Treat-ments	No. of plots	Age and month of harvest: 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	1.5	18.9	31.3	37.3	41.9	41.8	42.1	47.1	55.7	58.8	42.6
A1	5	2.7	43.1	83.1	84.7	89.2	96.3	104.1	100.2	98.5	88.6	72.8
B1	5	See A1	51.6	105.3	100.3	112.4	113.4	98.5	112.2	100.2	93.8	76.0
C1	5	"	43.5	110.8	118.4	127.6	124.8	120.0	132.1	133.7	130.5	92.9
A2	5	"	24.7	68.6	73.0	79.5	90.5	68.7	84.5	105.9	91.4	70.8
B2	5	"	See A1	93.2	95.8	95.1	112.2	108.5	116.8	115.0	119.0	86.8
C2	5	"	See B1	106.2	102.7	123.7	116.5	119.0	130.6	123.8	112.4	97.6
A3	5	"	See A2	49.7	51.5	53.0	64.8	76.7	94.4	88.0	96.7	70.6
B3	5	"	See A1	See A1	See A1	See A1	81.4	102.6	112.7	125.4	110.5	82.0
C3	5	"	See A1	See B2	See B2	See B2	104.1	128.2	143.0	147.7	124.8	106.6
Avg.	50	2.5	38.7	81.0	83.0	90.3	94.6	96.9	107.4	109.4	102.6	79.9
S.D.		.8	8.0	8.0	11.6	11.4	12.8	11.7	12.9	15.5	20.3	12.7
C.V.		32.8	20.6	9.9	13.9	12.6	13.5	12.1	12.0	14.2	19.8	15.9
M.d.r.		.8	*	*	*	*	16.4	15.0	16.6	19.9	26.1	16.3

TABLE 18

TOTAL DRY WEIGHT — TONS PER ACRE

Treat-ments	No. of plots	Age and month of harvest: 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	.26	3.57	7.53	10.07	11.57	11.43	11.97	13.79	16.05	16.13	12.73
A1	5	.44	6.98	20.12	23.12	24.05	25.72	30.44	30.13	26.88	24.90	21.32
B1	5	See A1	7.81	24.23	27.31	30.88	31.45	28.06	33.88	28.23	26.89	22.59
C1	5	"	6.63	24.56	30.23	33.91	34.41	34.11	39.98	38.05	37.97	27.79
A2	5	"	4.63	15.25	18.94	21.04	24.00	19.66	25.38	30.34	26.56	20.74
B2	5	"	See A1	21.01	24.96	26.04	30.30	31.28	35.34	33.66	34.42	25.57
C2	5	"	See B1	23.50	27.07	33.85	31.62	33.49	39.38	35.52	32.27	29.03
A3	5	"	See A2	12.65	14.09	14.80	17.67	20.06	27.09	26.15	28.07	21.22
B3	5	"	See A1	See A1	See A1	See A1	22.24	28.25	33.23	36.77	32.23	24.61
C3	5	"	See A1	See B2	See B2	See B2	27.71	34.96	41.82	43.29	36.72	32.73
Avg.	50	.42	6.24	18.61	21.97	24.50	25.66	27.23	32.00	31.50	29.62	23.83
S.D.		.13	1.26	1.98	3.10	3.18	3.78	3.15	3.60	4.81	6.33	3.90
C.V.		31.0	20.0	10.6	14.1	13.0	14.7	11.6	11.3	15.3	21.4	16.4
M.d.r.		—	*	*	*	*	4.9	4.1	4.6	6.2	8.1	5.0

TABLE 19

TONS MILLABLE CANE PER ACRE (T.C.A.)

Treat-ments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	7.5	20.4	27.5	32.1	33.5	34.1	36.9	45.4	51.1	36.9
A1	5	—	22.9	61.7	65.7	72.5	81.7	90.2	85.5	86.6	79.2	65.0
B1	5	—	27.9	79.4	78.8	91.3	95.5	86.1	98.2	87.9	84.9	68.7
C1	5	—	22.4	81.6	92.4	103.7	103.8	102.4	113.3	114.8	119.3	85.2
A2	5	—	12.2	48.6	55.1	63.2	76.0	59.0	70.9	90.6	81.1	64.1
B2	5	—	See A1	68.2	74.5	76.8	93.6	93.1	100.6	99.8	105.9	78.7
C2	5	—	See B1	78.3	80.1	98.7	96.2	102.6	113.0	109.5	100.9	90.2
A3	5	—	See A2	36.1	39.5	42.9	53.8	60.4	77.2	74.5	86.5	64.8
B3	5	—	See A1	See A1	See A1	See A1	67.6	85.2	95.2	107.8	98.7	76.2
C3	5	—	See A1	See B2	See B2	See B2	86.5	108.3	122.9	129.9	113.2	99.9
Avg.	50	—	20.2	59.3	64.2	72.7	78.8	82.1	91.4	94.7	92.1	72.9
S.D.		—	5.44	6.68	8.86	8.82	10.98	10.02	11.41	14.00	18.56	12.02
C.V.		—	26.9	11.3	13.8	12.1	13.9	12.2	12.5	14.8	20.2	16.5
M.d.r.		—	*	*	*	*	14.1	12.9	14.6	18.0	23.9	15.4

TABLE 20

YIELD PER CENT CANE (Y%C) FROM LIVE CANES ONLY

Treat-ments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	—	6.7	9.0	9.8	10.5	12.3	12.3	9.7	11.5	13.6
A1	5	—	—	7.2	9.7	9.8	9.2	12.2	12.5	10.8	12.2	12.6
B1	5	—	—	5.6	8.8	9.8	10.0	11.3	12.6	10.6	11.9	13.6
C1	5	—	—	4.4	7.3	8.6	9.6	11.6	12.5	11.0	12.4	13.8
A2	5	—	—	5.5	8.4	9.5	9.3	12.2	13.4	11.0	12.2	13.2
B2	5	—	—	5.2	8.3	9.9	9.9	12.0	13.2	11.3	12.3	13.9
C2	5	—	—	4.5	7.9	9.6	9.7	11.4	12.5	10.9	11.9	13.5
A3	5	—	—	7.7	9.9	10.3	10.9	10.1	11.7	11.3	11.7	13.3
B3	5	—	—	See A1	See A1	See A1	10.3	11.0	12.3	11.7	12.3	13.9
C3	5	—	—	See B2	See B2	See B2	9.7	11.3	12.3	12.0	12.9	14.1
Avg.	50	—	—	5.8	8.7	9.7	9.9	11.5	12.5	11.0	12.1	13.5
S.D.		—	—	.81	.60	.72	.89	.76	.65	.59	.77	.55
C.V.		—	—	14.0	6.9	7.4	9.0	6.6	5.2	5.4	6.4	4.1
M.d.r.		—	—	*	*	*	ns	1.0	.8	.8	ns	.7

TABLE 21

TONS REDUCING SUGARS PER ACRE

Treatments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	.18	.23	.22	.23	.19	.15	.21	.29	.27	.12
A1	5	—	.59	.71	.54	.56	.58	.32	.41	.62	.42	.24
B1	5	—	.78	1.12	.80	.84	.71	.29	.40	.53	.42	.21
C1	5	—	.67	1.49	1.30	1.05	.75	.39	.51	.70	.49	.26
A2	5	—	.27	.64	.48	.54	.60	.20	.33	.53	.35	.20
B2	5	—	See A1	.93	.75	.61	.62	.37	.47	.59	.48	.26
C2	5	—	See B1	1.39	1.02	.86	.71	.43	.51	.65	.50	.25
A3	5	—	See A2	.32	.30	.27	.32	.37	.45	.37	.44	.19
B3	5	—	See A1	See A1	See A1	See A1	.44	.40	.53	.55	.42	.20
C3	5	—	See A1	See B2	See B2	See B2	.62	.48	.60	.59	.52	.28
Avg.	50	—	.53	.85	.68	.62	.56	.34	.44	.54	.43	.22
S.D.		—	.14	.25	.21	.14	.14	.08	.10	.12	.10	.04
C.V.		—	26.4	29.4	30.9	22.6	25.0	23.5	22.7	22.2	23.3	18.2
M.d.r.		—	*	*	*	*	.18	.11	.13	.16	.13	.06

TABLE 22

TONS SUCROSE PER ACRE

Treatments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	.37	1.98	3.21	3.94	4.20	4.94	5.56	5.97	6.06	5.40
A1	5	—	.68	6.16	8.14	8.82	9.63	13.35	12.88	10.92	10.23	9.58
B1	5	—	.67	6.94	9.38	10.82	11.77	12.25	15.16	11.67	11.19	10.17
C1	5	—	.47	6.41	9.44	11.44	12.45	14.66	17.10	15.84	16.08	12.97
A2	5	—	.59	4.04	6.35	7.25	8.75	8.56	10.99	12.14	11.24	9.39
B2	5	—	See A1	5.66	8.32	9.18	11.53	13.49	15.58	13.99	14.13	11.35
C2	5	—	See B1	6.14	8.76	11.64	11.69	14.45	17.40	15.09	13.62	13.77
A3	5	—	See A2	3.91	4.99	5.76	6.77	7.72	10.66	10.56	11.13	9.52
B3	5	—	See A1	See A1	See A1	See A1	8.48	11.37	13.70	15.53	13.79	11.32
C3	5	—	See A1	See B2	See B2	See B2	10.31	14.58	17.93	18.22	15.34	14.63
Avg.	50	—	.61	5.16	7.32	8.60	9.56	11.54	13.70	13.00	12.28	10.81
S.D.		—	.18	.71	1.09	1.20	1.47	4.40	1.65	1.99	2.78	1.88
C.V.		—	29.5	13.8	14.9	14.0	15.4	38.1	12.0	15.3	22.6	17.4
M.d.r.		—	*	*	*	*	1.89	5.66	2.11	2.56	3.55	2.42

TABLE 23

TONS TOTAL SUGARS PER ACRE

Treat-ments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	.57	2.32	3.60	4.37	4.61	5.36	6.07	6.57	6.65	5.80
A1	5	—	1.31	7.19	9.11	9.84	10.72	14.38	13.97	12.11	11.19	10.33
B1	5	—	1.49	8.43	10.66	12.23	13.11	13.18	16.36	12.82	12.20	10.83
C1	5	—	1.16	8.24	11.24	13.08	13.86	15.83	18.51	17.37	17.50	13.92
A2	5	—	.90	4.90	7.21	8.18	9.78	9.21	11.89	13.30	12.18	10.08
B2	5	—	See A1	6.88	9.51	10.28	12.75	14.57	16.87	15.32	15.35	12.20
C2	5	—	See B1	7.86	10.24	13.12	12.97	15.64	18.83	16.53	14.85	14.74
A3	5	—	See A2	4.43	5.53	6.33	7.45	8.50	11.67	11.48	12.15	10.22
B3	5	—	See A1	See A1	See A1	See A1	9.37	12.38	14.96	16.90	14.93	12.12
C3	5	—	See A1	See B2	See B2	See B2	11.48	15.83	19.48	19.77	16.66	15.67
Avg.	50	—	1.17	6.28	8.39	9.67	10.61	12.49	14.86	14.22	13.37	11.59
S.D.		—	.31	.81	1.23	1.33	1.58	1.48	1.79	2.12	2.97	2.00
C.V.		—	26.5	12.9	14.7	13.8	14.9	11.8	12.0	14.9	22.2	17.3
M.d.r.		—	*	*	*	*	2.03	1.91	2.29	2.72	3.82	2.58

TABLE 24

TONS COMMERCIAL SUGAR PER ACRE (T.S.A.)

Treat-ments	No. of plots	Age and month of harvest										
		3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	—	—	1.4	2.5	3.2	3.5	4.2	4.5	4.5	5.9	5.0
A1	5	—	—	4.4	6.3	7.1	7.6	11.0	10.6	9.4	9.6	8.1
B1	5	—	—	4.5	7.0	8.9	9.6	9.6	12.4	9.3	10.1	9.3
C1	5	—	—	3.6	6.8	8.9	9.9	11.9	14.1	12.6	14.9	11.7
A2	5	—	—	2.7	4.7	6.0	7.1	7.2	9.5	9.9	9.8	8.4
B2	5	—	—	3.5	6.2	7.6	9.3	11.0	13.3	11.2	13.1	10.9
C2	5	—	—	3.4	6.3	9.4	9.3	11.7	14.2	12.0	12.0	12.2
A3	5	—	—	2 7	3.9	4.4	5.9	6.1	9.0	8.4	10.1	8.7
B3	5	—	—	See A1	See A1	See A1	6.9	9.4	11.7	12.6	12.1	10.6
C3	5	—	—	See B2	See B2	See B2	8.4	12.3	15.1	15.6	14.5	14.0
Avg.	50	—	—	3.3	5.5	6.9	7.7	9.4	11.5	10.5	11.2	9.9
S.D.		—	—	.65	.89	.98	1.30	1.22	1.52	1.64	2.47	1.58
C.V.		—	—	19.7	16.2	14.2	16.9	13.0	13.2	15.6	22.1	16.0
M.d.r.		—	—	*	*	*	1 7	1.6	1.9	2.1	3.2	2.0

TABLE 25

POUNDS NITROGEN PER ACRE FOUND IN TOTAL DRY WEIGHT

Treat-ments	No. of plots	Age and month of harvest 3 mos. Feb.	6 mos. May	9 mos. Aug.	10 mos. Sept.	11 mos. Oct.	12 mos. Nov.	15 mos. Feb.	18 mos. May	21 mos. Aug.	24 mos. Nov.	27 mos. Feb.
X	5	6.9	41.1	44.9	44.9	45.1	42.1	45.7	46.3	49.8	48.9	35.6
A1	5	13.7	106.4	110.2	99.6	95.7	102.5	97.3	85.2	76.2	68.0	56.0
B1	5	See A1	157.8	170.2	144.2	150.1	135.1	105.7	104.0	82.9	72.4	52.1
C1	5	"	150.3	194.3	191.8	202.4	169.0	150.6	136.4	118.6	99.2	64.8
A2	5	"	48.1	109.4	92.0	93.9	98.3	70.9	84.3	86.3	67.4	5.41
B2	5	"	See A1	150.6	132.7	119.3	122.1	117.8	109.8	92.8	90.6	63.4
C2	5	"	See B1	204.6	178.8	194.8	161.3	148.5	133.6	110.2	86.1	7.15
A3	5	"	See A2	62.6	56.5	52.2	79.5	101.9	106.0	78.7	72.2	48.5
B3	5	"	See A1	See A1	See A1	See A1	100.9	128.5	117.3	104.2	75.9	53.8
C3	5	"	See A1	See B2	See B2	See B2	137.2	159.0	155.0	128.5	95.9	76.3
Avg.	50	13.0	102.7	130.9	117.6	119.1	114.8	112.6	107.8	92.8	77.7	57.3
S.D.		3.69	17.20	17.63	14.90	13.05	16.47	16.95	18.26	14.38	13.98	10.26
C.V.		28.4	16.7	13.5	12.6	11.0	14.3	15.1	16.9	15.5	18.0	17.9
M.d.r.		—	*	*	*	*	21.2	21.8	23.4	18.5	17.9	13.2

FOR REVIEWING

History of the Entomology Department Experiment Station, H. S. P. A. 1904-1945

By C. E. PEMBERTON

CONTENTS

In the latter half of the year 1900, Dr. R. C. L. Perkins, a young graduate of the University of Oxford, then engaged by the British Association for the Advancement of Science in an investigation of the land fauna of the Hawaiian Islands, observed and captured a leaf hopper at a light in his room at Waialua, Oahu. It was a species unfamiliar to him though he had been collecting insects almost continuously from all of the islands of the Hawaiian group from 1892 to 1897 and had amassed a comprehensive collection of leaf hoppers during that time. Then E. G. Clarke, Field Assistant of the Experiment Station, H.S.P.A., found this same species of leaf hopper on sugar cane at the Experiment Station in Honolulu. Meanwhile it was building up on cane elsewhere, and by the end of 1901 or early in 1902 it was doing serious damage on Oahu. A few months later specimens from the Island of Kauai were submitted to Perkins for identification. In a report written by him on November 15, 1902, he stated: "This small insect is highly injurious to cane and its destructiveness threatens to exceed that of the cane borer."

By the middle of 1903, this insect was found on all of the Islands in the Territory where sugar cane was grown and the planters abruptly realized that a serious menace threatened their thriving industry. By 1904 a considerable drop in the total yield of sugar occurred. This grave situation prompted the Hawaiian Sugar Planters' Association to expand its Experiment Station to include a staff of entomologists employed on a full-time basis.

Accordingly at a formal meeting on April 21, 1904, the Board of Trustees, H.S.P.A., adopted a recommendation of its Experiment Station Committee that a Division of Entomology be established at the Experiment Station. A special committee consisting of W. M. Giffard, G. M. Rolph and E. D. Tenney was appointed to perfect the organization. This committee completed all plans during the ensuing month; suitable quarters for a staff were soon constructed and during August and September of the same year a group of capable entomologists was appointed. The staff consisted of Dr. Perkins, Superintendent, O. H. Swezey, Assistant Entomologist, G. W. Kirkaldy, Assistant Entomologist, F. W. Terry, Assistant Entomologist and two Consulting Entomologists, Alexander Craw and Albert Koebele. Messrs. Craw and Koebele were jointly assigned to the service of the Territorial Government and the H.S.P.A. by mutual agreement between the two organizations, the latter assuming half the salaries of these two men. Craw as Superintendent of Entomology, Board of Agriculture and Forestry, took over all plant inspection work, while Koebele became Consulting Entomologist for both the Board and the H.S.P.A. All of these men except Dr. Swezey were at that time on the staff of the Territorial Board of Commissioners of Agriculture and Forestry. The H.S.P.A. was paying half the salaries of all but one.

The decision of the H.S.P.A. to establish a Division of Entomology at the Experiment Station was thus primarily impelled by the leaf-hopper visitation. Their reliance on entomologists at this crucial period in their history was supported by good precedents already manifested in the Islands. The control of insect pests by using their natural enemies had been demonstrated by Koebele to be a sound and practicable method. It was during 1888-89, while he was in

the service of the United States Department of Agriculture, that he effected the classic control of the cottony cushion scale in California through the introduction of a lady beetle from Australia. Also during the long period between 1893 and 1903, while employed under the direction of the Commissioner of Agriculture of Hawaii, he introduced many beneficial insects into the Islands from several

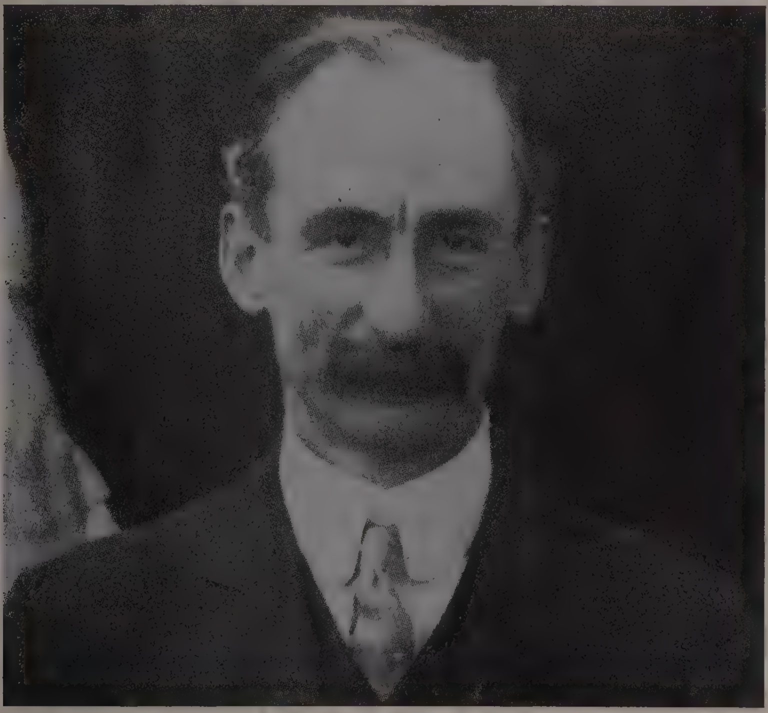

Fig. 1. Dr. R. C. L. Perkins.

foreign countries and in some cases their effectiveness proved beyond any doubt that the biological method of insect control had great merit. It was also a fortunate circumstance during these early and anxious days of leaf-hopper depredations that the planters had the wise councils of Dr. Perkins, whose long experience as an entomologist in Hawaii and broad knowledge in his profession particularly fitted him to advise and guide them in their final action.

The selection of the staff above listed proved a wise one. They were men of exceptional ability and thoroughly trained. The large economic results attending their work during the next few years amply demonstrated the value of maintaining a fully staffed Division of Entomology composed of carefully selected entomologists. Down through the years this policy has been fully justified.

The Sugar-Cane Leaf Hopper
(*Perkinsiella saccharicida* Kirkaldy)

At the time the Entomology Division was formally organized as a part of the Experiment Station, H.S.P.A., much information had already been obtained

about the leaf hopper by several entomologists. Dr. Perkins, then Assistant Entomologist for the Board of Commissioners of Agriculture and Forestry, and D. L. Van Dine, Entomologist of the Hawaii Agricultural Experiment Station, had both published bulletins covering the history of the hopper, its habits, damage to cane, and natural enemies already in Hawaii. It had also been identified and named by Mr. Kirkaldy, a specialist in Hemiptera, who resided in England. Kirkaldy found it different from any other hopper known to him or described in literature. He described it under the above name in the June 1903 issue of *The Entomologist*, a magazine published in London. Shortly before this Dr. L. O. Howard, Chief Entomologist, United States Department of Agriculture, had informed Mr. Van Dine of Kirkaldy's conclusions and proposed name for this insect. Kirkaldy also determined beyond doubt that our cane hopper was closely allied to the species then known to attack cane in Java. These were important facts in tracing the origin of our cane hopper. But still more important was information obtained by Dr. Perkins when inspecting some sugar-cane cuttings imported from Queensland. He found viable leaf-hopper eggs in the cuttings and living young hoppers in the paper-wrapped packages, all of which he destroyed. He then sent specimens of adult hoppers taken on cane in Hawaii to Australian entomologists for comparison with the species there, and in return received specimens of cane hoppers collected at Cairns, Queensland, by James Clark, who stated that the species occurred on cane there but did no noticeable damage.

Perkins compared these with Hawaiian specimens and found them identical. Such was the chain of circumstances which ultimately led to victory.

With the establishment of proof that our cane hopper occurred on cane in Queensland and was not considered harmful there, the immediate need for a study of this insect in that country was clearly indicated. Plans were formulated for this work. Dr. Swezey was in Ohio where he had already studied certain parasites of leaf hoppers in that State. His published results attracted the attention of Dr. Howard, who suggested that Koebele visit Swezey and introduce the leaf-hopper parasites of Ohio to Hawaii. This he did. But in addition to that, he learned much from his visit about leaf-hopper parasites in general. The outcome was the employment of Dr. Swezey on the Division of Entomology staff. He arrived in August 1904 to take over the important work of receiving, breeding and distributing parasites imported from outside countries.

Early in 1904 Koebele came to Honolulu and on May 11 of that year he and Perkins left for Queensland. As mentioned above, this was several months before the H.S.P.A. had fully organized their entomological staff. Almost immediately upon arrival in Brisbane and Bundaberg in South Queensland they found the same leaf hopper on cane as in Hawaii and also observed a number of different parasites. It was at Bundaberg during June, only a few weeks after they left Honolulu, that Koebele discovered the minute egg parasite which was destined to play a large part in the control of the leaf hopper in Hawaii. During the next few months they found this parasite in various parts of Queensland. Several shipments were made to Honolulu; but the difficulties and slowness of transportation at that time usually resulted in the material arriving dead or weak. Mr. Terry kept notes on the condition and disposition of these shipments after their arrival in Honolulu. He listed 3 shipments, however, received in August,

October, and November, 1904, respectively, from which egg parasites were reared and liberated at "Oahu Plantation".

Finally Dr. Perkins brought back a breeding cage stocked in Australia with growing cane, hoppers and parasites. He arrived December 14, 1904. On January 26-27, 1905, he discovered a few females of this minute and almost microscopic parasite in the cage. Half was liberated and the remainder saved for indoor breeding. Under Dr. Perkins' watchful care the latter multiplied rapidly in breeding cages which he devised at the Station. Soon it was possible

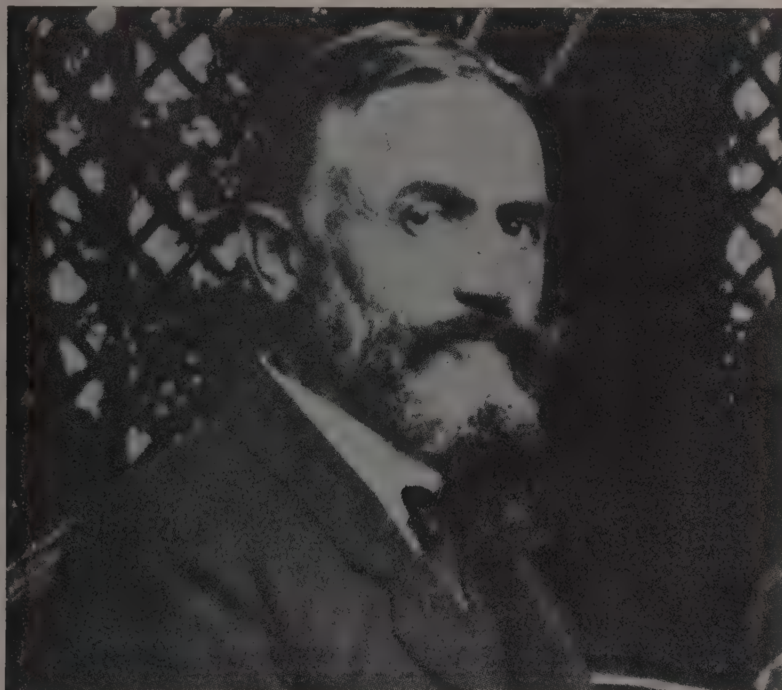

Fig. 2. Albert Koebele.

to make liberations on the plantations and by the end of 1905 the parasite was found in some of the cane areas. During 1906 it became widespread and the following year the leaf hopper became greatly reduced. In November 1905, Perkins published his description of this parasite, which was new to science, under the name *Paranagrus optabilis*. This was described in Bulletin 1, Part 6, Division of Entomology, Experiment Station, H.S.P.A.

During the early efforts to control the leaf hopper with parasites, several other species were introduced and established in the Islands; but they were not as effective as the *Paranagrus*. Among these was a parasite later described and named by Perkins as *Anagrus frequens*. Superficially it closely resembled the *Paranagrus*. This is the first parasite shipped by Koebele and Perkins from Australia that was actually found established in cane on Oahu and must have developed from one or more of the first liberations which Terry mentioned in his

notes. This parasite can be found to the present day, but most frequently on corn where it parasitizes the corn leaf hopper, *Peregrinus maidis* (Ashm.).

Koebele returned to Honolulu from Australia early in 1905, but stopped over in Fiji for a month to examine the sugar-cane leaf hopper there, which was slightly different from the species established in Hawaii. Here he obtained and introduced into Hawaii another parasite which Perkins later described and named *Ootetrastichus beatus*. This parasite had already been noted by Perkins and Koebele in Queensland and was considered important. Koebele arrived from Fiji on April 5, 1905. The parasite was liberated on cane at the Experiment Station where it soon became established and was then spread throughout the Territory.

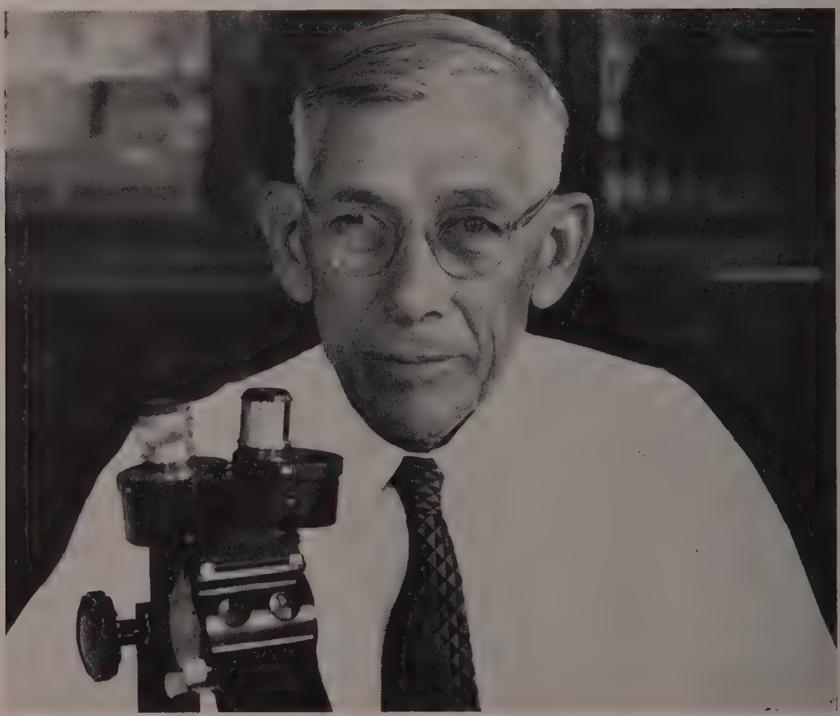

Fig. 3. Dr. O. H. Swezey.

Thus during 1905 three definite parasites of the leaf hopper became established in Hawaii as a result of the Koebele-Perkins expedition to Australia and Fiji. Other parasites had been tried but failed. From the studies of Swezey and Koebele in Ohio and Koebele and Perkins during their expedition, it was felt that still other parasites of importance could be found and established in the Islands. Koebele's health was failing and Frederick Muir was engaged to take over the arduous foreign work which Koebele had been conducting for more than ten years.

Dr. Muir became a member of the entomology staff on September 1, 1905, to serve as Assistant Entomologist under Dr. Perkins. He had been an ardent

collector and student of insects in his early days and had contributed much valuable material to the British Museum during residence in East Africa while still a young man. He was employed upon the recommendation of Dr. David Sharp, then Curator of Insect Collections, University Museum of Zoology at Cambridge, England.

Muir remained in Honolulu only a few weeks and then left for Fiji during October to study the natural enemies of the sugar-cane leaf hopper of that region. This hopper, *Perkinsiella vitiensis*, is very closely related to the species in Hawaii and it was believed that parasites from Fiji would prove useful in Hawaii. Muir soon reported that the Fijian leaf hopper was nowhere sufficiently numerous to be destructive to sugar cane and that its parasites were in general quite similar to those found by Koebele and Perkins in Australia. In the course of his investigations he introduced one more parasite into Hawaii which became established. This parasite, *Haplogonatopus vitiensis*, so named by Perkins, had been discovered by Koebele in March 1905. Muir shipped a cage of living leaf hoppers which arrived in Honolulu March 7, 1906. From these hoppers a single female of this parasite was obtained. It was carefully handled at the Experiment Station and from its progeny colonies were built up and sent to all of the plantations where they became permanently established. For various reasons it proved to be of secondary importance.

Muir remained in Fiji several months. He returned to Honolulu for a short period and then left for China in July 1906 to study sugar-cane leaf hoppers and their enemies in that country. Here also he found sugar-cane leaf hoppers scarce and controlled by the same complex of parasites occurring in Fiji and Australia. After much difficulty he succeeded in discovering at Wei Chou a parasite which Perkins named *Pseudogonatopus hospes*. Muir succeeded in shipping this alive to Honolulu during December 1906 and early in 1907. The species was multiplied in cages at the Experiment Station and distributed to plantations in June, July, and August 1907. It became established from these liberations but it was not until March 24, 1916, nine years later, that it was actually found in Hawaiian cane fields, after which it became quite common. However, it never effected a large control of the leaf hopper.

Between 1907 and 1916 Dr. Muir traveled extensively in the Malay Archipelago, including Japan, Formosa, Malay States, New Guinea and the Philippine Islands in connection with other work, but he kept in mind the need for more leaf-hopper parasites. In all these regions he noted the comparative scarcity of leaf hoppers on sugar cane and invariably reported the presence of parasites similar to those already introduced into Hawaii. In Formosa he found one that seemed promising and in February 1916 brought it to Honolulu alive. This was later described and named by P. H. Timberlake as *Ootetrastichus formosanus*. It was multiplied at the Experiment Station and distributed to the plantations where it became definitely established during the next few years. It proved additionally helpful to the other parasites already established.

Though the several leaf-hopper parasites which had been successfully introduced into Hawaii by Koebele, Perkins or Muir between 1904 and 1916 effected an excellent control of the pest on most of the sugar plantations in Hawaii, large outbreaks continued to occur periodically in some areas, especially where rainfall was normally heavy many months of each year. This was particularly the case

on the wet plantations of the Island of Hawaii and occasionally on other plantations. These outbreaks required constant attention, in addition to other serious insect problems confronting the entomologists. Owing to poor health Koebele and Perkins were relieved from active duty in 1910 and 1915 respectively and given the status of Consulting Entomologists. The staff became shorthanded and several more men were employed. This new personnel and the services rendered will be discussed later. However, the leaf hopper remained a major problem on the wet plantations and it was deemed advisable to assign one or more men continuously to this project.

On February 1, 1919, C. E. Pemberton, then with the U. S. Bureau of Entomology, was employed as Assistant Entomologist and assigned to study the ecology of the leaf hopper in the Hilo District of the Island of Hawaii and particularly at Olaa Sugar Company, Ltd., where the hopper was especially troublesome. Insecticidal and other control methods, after elaborate trial, proved futile and ample evidence was obtained to confirm the belief that heavy and frequent rains seriously interfered with the full operation of the important egg parasites introduced by Koebele and Perkins. Beneficial insects which could cope with such a climate were much needed

The search for more natural enemies of the leaf hopper was resumed during 1919. Dr. F. X. Williams, who joined the Entomology Division in May 1916, left for Australia on February 10, 1919, for further leaf-hopper investigations. He returned on August 19 with several lots of beneficial insects from Australian cane fields, including certain carabid beetles which he observed feeding on leaf hoppers. These were liberated at Olaa Sugar Company but apparently failed to survive. On May 18, 1919, Dr. Muir also went to Australia to take up further studies of the leaf hopper in Queensland sugar-cane fields. It was nearly a year later that he observed collapsed leaf-hopper eggs in the midribs of cane leaves and further study disclosed the cause of this condition. He noticed the small hemipterous insect *Cyrtorhinus mundulus* (Bredd.) inserting its proboscis into cavities in the cane leaves where leaf-hopper eggs had been laid. Dissection of the leaves revealed many eggs which had been sucked dry by the bug. Muir returned to Honolulu on June 21, 1920, with a number of these bugs alive in a cage. Since this insect belongs to a family of insects, many of which are serious plant pests, it required careful study before liberation in Hawaiian cane fields could be done with complete freedom from risk. Furthermore this insect was known in Java cane fields and listed as a minor cane pest without any certain knowledge of its habits but purely because of its constant presence on sugar cane; it was also known in Fiji. Muir and Pemberton conducted several tests with elaborate care and found that none of the bugs survived on even the most succulent of cane leaves unless also given leaf-hopper eggs for food. They fed only on the eggs. A few survived the test and were finally taken to Ewa Plantation on July 19 and July 24, 1920, and liberated in a cane field where leaf hoppers were abundant. Muir predicted that it would thrive in the wet regions of Hawaii, since he found it associated with leaf hoppers in all cane regions examined in Queensland and Fiji, including sections with high annual rainfall.

Pemberton then left Honolulu for Fiji on July 28, 1920, to obtain large lots of *Cyrtorhinus*. During September, October and November of the same year 6 cages well stocked with this insect were sent to Honolulu. An abundance of

material was thus secured for liberation on several plantations and some was saved for multiplication in cages at the Experiment Station and on some of the Oahu plantations. H. T. Osborn, who joined the entomological staff on July 1, 1913, was specially assigned to this work and large quantities of the bug were distributed to the plantations. It soon became established and by 1923 was generally present in all cane fields in the Territory. From 1923 on the leaf hopper subsided to a level of unimportance and has remained so to the present date. Thus ended a chapter of struggle lasting over 20 years. In summarizing the results H. P. Agee once wrote, "The value of this work in economic entomology cannot be measured in millions of dollars, regardless of how high we carry the count. It saved an industry that has been the mainstay of modern Hawaii — a Hawaii that brings about rich advances in Pacific betterment; developments that are cultural, sociological, industrial, scientific in character — a Hawaii that offers examples in human progress that may be helpful to much of the world at large".

A full account of the leaf hopper and its control has been published by Dr. Swezey in Bulletin No. 21, Entomological Series, Experiment Station, H.S.P.A., January 1936 under the title "Biological Control of the Sugar Cane Leaf Hopper in Hawaii". This includes a bibliography covering extensive literature on the subject.

The Sugar-Cane Beetle Borer
(*Rhabdoscelus obscurus* [Boisd.])

The second insect to receive major attention by the entomologists was the beetle borer. Like the leaf hopper it was also of foreign origin, but was known in Hawaii as early as 1865. A great deal of departmental activity centered about this pest from the beginning of the organization of the Division until comparatively recent years. It never offered a serious threat to the sugar industry and consequently was not greatly feared. However, it was a source of constant complaint and was responsible for a very great loss of sugar through the years. Very conservative estimates placed the loss at from two to five per cent of the total crop, which amounted to at least a million dollars annually. Control by cultural or other artificial methods was practiced with some success and it was found that some cane varieties were much more resistant to borer attack than others, but the need for some satisfactory means of control applicable to all varieties of cane, growing under varied conditions, was obvious and again the entomologists turned to a parasitic or natural solution of the problem.

The principal work began in January 1907, when Muir, who was in South China, commenced a long search for this particular species of borer and any natural enemies which it might have. Muir's labors on this problem may be said to have finally ended on August 16, 1910, when he returned to Honolulu with a cage of living flies, which he found parasitizing the grubs of this beetle in Amboina, Ceram and New Guinea. The events which culminated in his return home with an effective parasite is a rare odyssey in the annals of entomological exploration because of the extent of time and travel involved and the difficulties and disappointments encountered before the project was successfully completed.

At the time Muir began this adventure there was some published information

concerning the borer. It received its name from specimens collected on New Ireland in 1835. In 1885 it was recorded from the Island of Larat and by 1895 literature referred to its presence in New Guinea. It was also known in Tahiti and was supposed to have reached Fiji from Hawaii. It had also reached North Queensland presumably in cane brought in from New Guinea. Muir thus had some grounds for suspecting that the native home of this borer was somewhere in New Guinea or the Malay Archipelago to the west. He began by spending

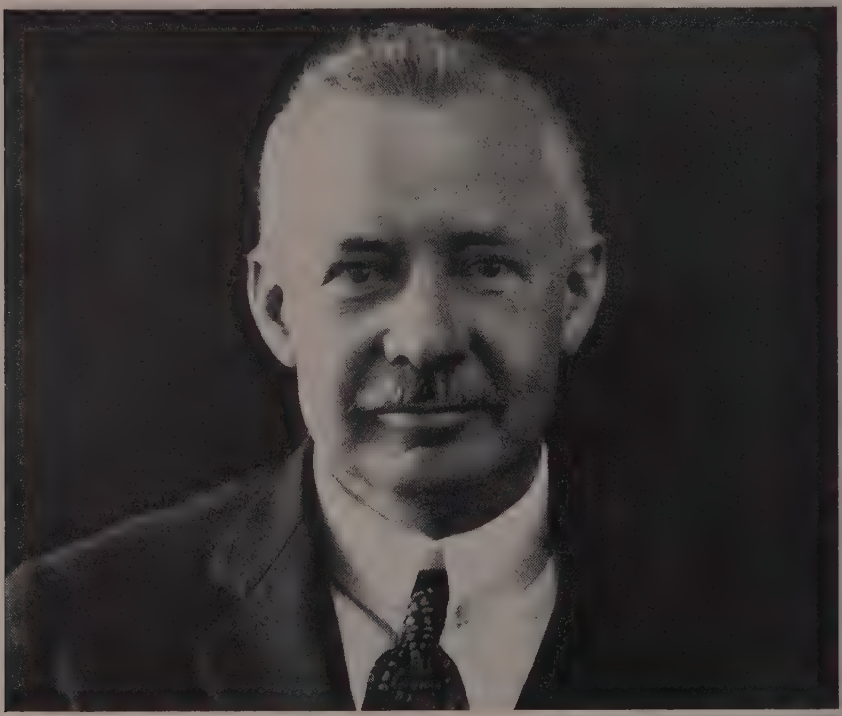

Fig. 4. Dr. F. A. G. Muir.

about two months in the Federated Malay States searching for the borer but found none. He then spent 10 weeks in West Java studying borers allied to the cane borer. Here he found no true parasites; but a number of predatory insects (Histeridae and Hydrophilidae) were observed feeding on the grubs of these related borers that he found in palms and banana stumps. Shipments of these were made to Honolulu; but were not attended with success. He failed to find our cane borer in Java.

Muir then went to Borneo in July 1907 to undertake similar borer studies. He failed to find the cane borer; but again found predatory insects similar to those found in Java which fed on other borer grubs occurring in palms and banana stumps. He remained in Borneo until October 1, 1907 and then returned to Java to ship more of these predatory insects to Honolulu. These failed. Having found no promising natural enemy of various borers which he studied in Java and Borneo, Muir decided to move into regions where the cane borer was known

to occur and on October 1, 1907, he left Batavia, Java and journeyed some 1,500 miles eastward to the Island of Amboina, where he had reason to believe the borer could be found. Arriving at Amboina on October 9, he spent 6 weeks searching for the borer in sugar cane, but failed to find it. He then departed for Larat, a six-day steamer trip to the southeast, where the cane borer had been found by a wandering naturalist in 1885. Arriving at Larat on November 29, 1907, he soon found the cane borer in sugar cane and in sago-palm leaf stalks and betel-nut palm stems. A month's study of these revealed no parasites and he returned to Amboina about January 9, 1908. Having learned at Larat that the borer occurred commonly in sago-palm leaf stalks, he renewed his search for borer parasites on Amboina and was rewarded with success as soon as he visited a sago-palm swamp. Here he immediately found the borer in the palm-leaf stalks and also discovered that from 25 to 90 per cent of the borer grubs were parasitized by a tachinid fly, which was later described and named *Ceromasia sphenophori* by Dr. J. Villeneuve. This is the parasite which ultimately checked the borer ravages in Hawaii. It is now known as *Microceromasia sphenophori* Vill.

To import this fly from Amboina to Honolulu alive in those days was a disheartening problem. Transportation was very slow and irregular and all material had to be sent to Macassar, Celebes, thence to Hong Kong and from there transshipped to Honolulu. Muir remained in Amboina eight months striving in various ways to surmount these difficulties. Several shipments of the fly were attempted but all failed. Mr. Terry had been sent out to Hong Kong to receive and send on the consignments from that point to Honolulu. Muir sent 18 consignments of beneficial insects in all, many of which were histerid beetles which he found preying on borer grubs. With Terry's aid in handling this material at Hong Kong many of these beetles or their larvae reached Honolulu alive and were liberated in Hawaiian cane fields, but were never seen again. None of the flies survived the trip. Finally in September 1908, Muir personally conducted a consignment of the flies from Amboina to Hong Kong, but all died en route.

Muir then decided to return east to the Island of Ceram to devise other means, if possible, by which the parasite could be introduced into Hawaii. He had as a companion J. C. Kershaw, who had the year before published an excellent book on the butterflies of Hong Kong. They worked together in Ceram for a month without success. Knowing that the cane borer occurred in New Guinea, Muir laid plans to investigate its parasites there, if such could be found. He returned again to Macassar and obtained transportation to Port Moresby, New Guinea, on April 9, 1909. Soon after reaching Port Moresby he found the borer in sugar cane some 15 miles inland and immediately discovered the same parasite, which he first found in Amboina. This he soon attempted to bring to Honolulu alive via Thursday Island and Brisbane, Queensland, but he was forced into a hospital with typhoid fever at Brisbane and his consignment of flies, which was transshipped to Honolulu by a friend, arrived dead. After 5 weeks hospitalization in Brisbane Muir returned to Honolulu to recuperate.

On January 8, 1910, Muir left Honolulu for Queensland to resume his labors on this problem. During the same month Mr. Kershaw was engaged on the entomology staff. A relay station for breeding the parasite was established at Mossman, North Queensland, with Kershaw in charge. Muir then proceeded

to Port Moresby again to obtain the parasite. A mail shipment to Kershaw failed and on April 22, 1910, Muir left Port Moresby for Mossman with a large consignment of parasite material in a living condition. After unexpected delays and other difficulties he finally reached Mossman with a good lot of living parasites. The borer being common in cane at Mossman, Kershaw had experienced no difficulty in having three large cages well stocked with borers awaiting Muir's arrival. This was on May 5. Some of these parasites were used to stock the cages for the production of a new generation. Though suffering from an attack of malaria at the time, Muir took the remainder of the parasites and departed for Fiji on the first available steamer. At Fiji, where the borer was numerous in cane, a cage containing borer-infested cane had been previously prepared by the Colonial Sugar Refining Company to await Muir's arrival. Upon reaching Fiji Muir immediately placed the parasites in the cage and then was forced to enter a hospital for treatment and rest because of his malarial condition. Kershaw reached Fiji from Mossman, Queensland, on August 9 with the remainder of the parasites and by then Muir had sufficiently recovered to depart for Honolulu with Kershaw's cages and the one he had already prepared in Fiji. Muir arrived at Honolulu August 16 with a good stock of living parasitic material and a month later Kershaw arrived from Fiji with more which he had reared in Fiji from a portion he kept out of the original lot brought by Muir.

These flies were multiplied at the Station in large cages and distributed to the plantations for more than two years, resulting in the establishment of this beneficial insect on all parts of Hawaii where sugar cane was grown, and, during the ensuing years, in the saving of millions of dollars.

A detailed account of this cane borer and its parasites is found in Bulletin No. 13, Entomological Series, Experiment Station, H.S.P.A., September 1916, by F. Muir and O. H. Swezey, entitled "The Cane Borer Beetle in Hawaii and Its Control by Natural Enemies."

For 20 years or more after this parasite was established in Hawaii, the entomologists continued to give the borer some attention owing to damage caused on many plantations where certain cane varieties, rat damage and necessary cultural practices favored its development in spite of the presence of the parasite. Attempts were made to find and establish more natural enemies. Osborn studied related borers of cane in Mexico during 1923 and introduced a parasitic fly (*Myiophasia metallica* Towns.) which he found parasitizing one of the cane borers there. It reached Hawaii alive in small numbers and was liberated at Honokaa, but did not become established. Williams left Honolulu August 1, 1922, for South America, visiting Panama, Ecuador, British Guiana and Brazil in search of certain beneficial insects, remaining away until July 28, 1924. During 1923 while on this trip, he investigated a South American borer (*Metamasius* sp.) for parasites and other natural enemies, but found no evidence of important control factors. During 1928 he visited Missouri and obtained and introduced into Hawaii several hundred little parasites (*Anaphoidea calendrae* Gahan) which parasitize the eggs of certain weevils somewhat related to our cane borer. These reached Hawaii in good condition and were liberated in suitable places but apparently did not find the eggs of the Hawaiian cane borer to their liking for there is no evidence that they became established.

On February 13, 1925, Pemberton left Honolulu for the Philippines and the

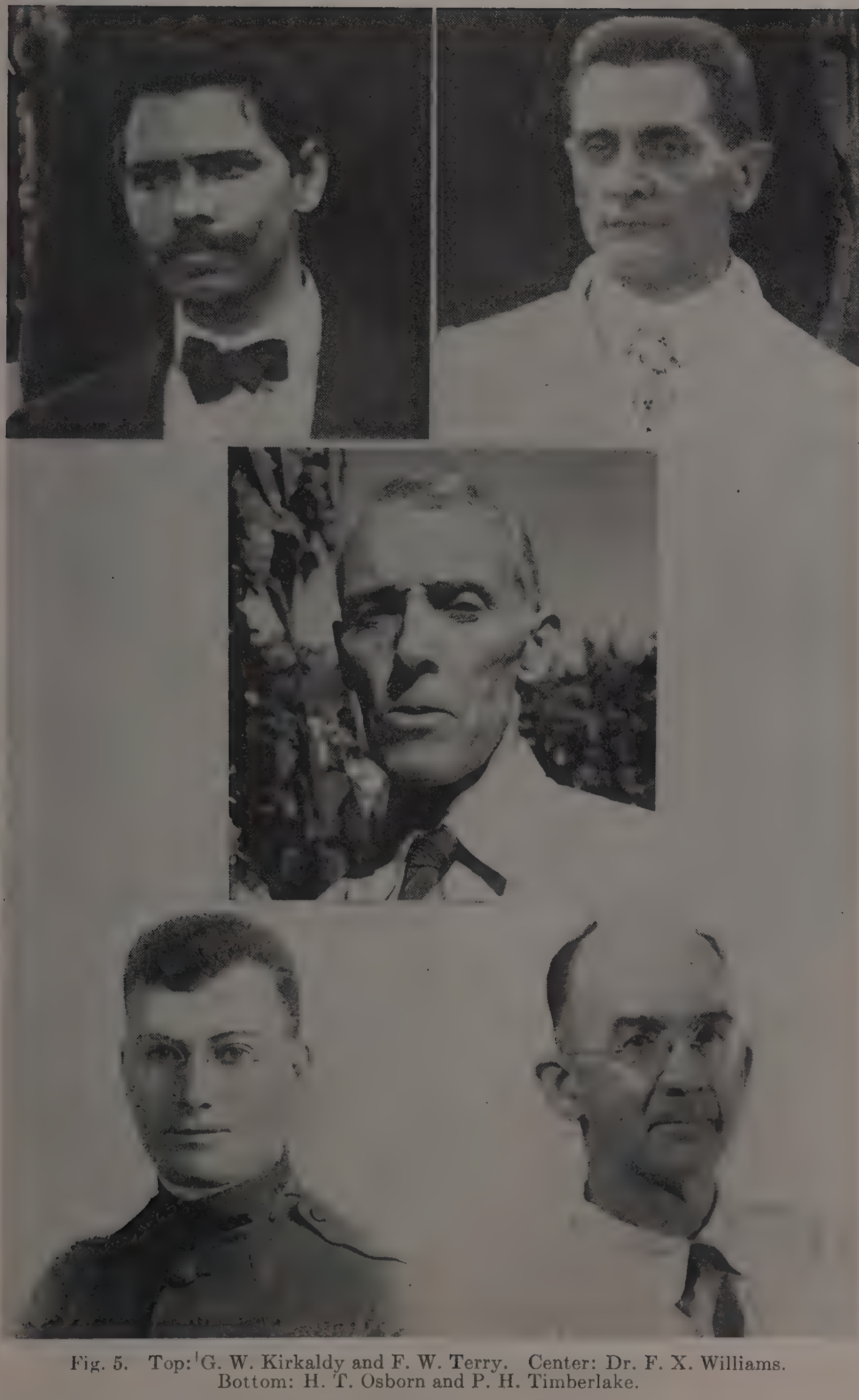

Fig. 5. Top: G. W. Kirkaldy and F. W. Terry. Center: Dr. F. X. Williams. Bottom: H. T. Osborn and P. H. Timberlake.

Malay Archipelago. He remained away until March 3, 1927, searching for natural enemies of borers related to the cane borer, which occurred mostly in wild palms in forest regions in the Philippines, Borneo, Java and Celebes. Several predatory enemies were found, in addition to a species of *Sporotrichum* fungus which was found rather effective in killing off large numbers of borers in many of the regions visited. The fungus and several species of predatory insects were introduced from the Philippines and Celebes, arriving in Hawaii in good condition. The fungus was propagated extensively and spread in cane fields, especially at Paauhau, Hawaii; but there is no evidence that Hawaiian conditions in the field are suitable for it. One of the predatory beetles, *Dactylosternum hydrophiloides* M'Leay, became established but has never become sufficiently abundant to prove of importance in Hawaii.

During 1928, 1929 and 1937 Pemberton visited New Guinea, New Britain, New Ireland and New Hanover on cane-collecting expeditions and searched further for enemies of this cane borer. However, throughout the New Guinea and adjacent island regions the only parasite of importance proved to be the one already introduced into Hawaii by Muir, though a related tachinid fly was found parasitizing the cane borer in palms in swamps in New Hanover. Nothing further was introduced into Hawaii.

The entomologists also carried on, intermittently through the years, local studies of this borer as it occurred under a wide variety of conditions on the several sugar plantations on each island in Hawaii. Much evidence was obtained to explain why it was more destructive in some areas than in others and why the extent of parasitism by the New Guinea fly fluctuated widely at different times and in different localities. All members of the staff participated in this work. R. H. Van Zwaluwenburg gave special attention to these problems as they occurred both at Kailua, Oahu and at Paauhau, Hawaii, while Pemberton spent 8 months at Paauhau on this general subject in collaboration with Raymond Elliott, Chemist, who by chemical analyses, accurately demonstrated the large sugar losses caused in cane fields where borer damage was heavy.

Swezey and others during the early days of the Experiment Station noted the pronounced difference in borer damage as found in the variety Yellow Caledonia, a cane with a relatively hard rind, compared with Badila and some others recognized as "soft" canes. During 1934 intensive studies were begun by the entomologists on cane varietal resistance to borer attack. In April of that year Dr. H. L. Lyon designed an instrument which could be used in the laboratory to measure the relative hardness of various canes. Two years later this was modified to a form adaptable to hand use in the field. With this a large amount of data were obtained in the field on the relative hardness of many cane varieties. It was soon demonstrated that a close correlation existed between the extent of borer damage in any given variety and the rind hardness recorded by the instrument. The use of such an instrument, variously modified, became standard routine by the geneticists, in recording the characteristics of all cane seedlings of promise which they were propagating. Canes of moderate-to-hard rind were favored in selection work, in conjunction with other desirable qualities. The final result has been the production of several new cane varieties having moderate-to-hard rinds which have supplanted in large measure the softer canes on all of the plantations. This varietal change, in combination with the constant opera-

tion of the New Guinea parasite, has brought the cane-borer problem in the Territory to one of very minor importance and the damage today is so small as to be hardly measurable.

The Anomala Beetle
(*Anomala orientalis* [Waterh.])

In October 1908, Dr. Lyon, then Pathologist of the H.S.P.A. Experiment Station, visited Honolulu Plantation Company to examine patches of failing sugar cane suspected of suffering from disease. He found no evidence of any specific disease, but many grubs, believed at that time to be those of the so-called "Japanese Beetle", *Adoretus sinicus* Burm., were observed about the roots of the cane. Again in October 1910, he re-examined the same areas and found no improvement. The areas of poor cane had expanded considerably and grubs were still very abundant in the soil in these spots. In June 1912, A. T. Speare, Assistant Pathologist, brought Dr. Muir some grubs from the same locality. A critical examination by Muir revealed that the grubs were different from those of the common "Japanese Beetle". Muir then visited the spot and succeeded in collecting some beetles which he sent to the British Museum where they were identified as *Anomala orientalis*, a beetle previously unknown in the Hawaiian Islands.

It is probable that this beetle entered Hawaii in soil from the Orient sometime prior to 1908. At that time soil was not excluded from entry into Hawaii and plants growing in soil from the Orient were frequently imported. During 1911 and 1912 plant inspectors often found white grubs in such soil from the Orient. At that time this beetle was known to occur only in Japan. Later Korea was determined as a habitat also.

Though this beetle was found to spread very slowly from the area at Honolulu Plantation Company where it was first seen, the damage it caused in the spots where found was very serious. The grubs ate the rootlets and bored into the rootstocks sufficiently to weaken greatly the cane stools and in many cases kill them outright. The insect was immediately recognized as a serious menace to the Hawaiian sugar industry.

Various chemical methods were investigated in efforts to control the grubs in the soil, but for many reasons they proved unsatisfactory. Again the entomologists turned to the biological or natural method for control. With positive evidence that the beetle was of Oriental origin, Muir departed for Japan on March 28, 1913, to look for parasites and other natural enemies. He was gone nearly 20 months, during which time he visited Japan, Java and Formosa. He had no difficulty finding *Anomala orientalis* in Japan and he also found several parasites and predators on the grubs of this beetle. He made a number of shipments of these, but most of the material arrived dead. However, two cages containing a species of *Tiphia* arrived in October and November 1913, respectively, with a total of 52 adults alive and a third cage stocked with the same insect reached Honolulu on October 8, 1914, with 65 alive. Muir had great hopes for this parasite. All were liberated on Oahu where the *Anomala* grubs were doing damage but the species failed to become established.

These disappointments led Muir to return to Japan in May 1915, to continue

his search for *Anomala* enemies. During July 1915, he shipped successfully to Honolulu 74 living *Craspedonotus tibialis* Schaum., a large carabid beetle which he considered a valuable predator on white grubs in Japan. These were liberated at Honolulu Plantation Company. Later attempts by Muir and Osborn to establish this beetle in Hawaii were made and though many living beetles reached Honolulu alive and were liberated, the species never became established.

Though *Anomala orientalis* does not occur in the Philippine Islands, a number of closely allied species are known. Since the work in Japan gave little promise of success, Muir decided to take up a study of *Anomala* parasites in the Philippines, being hopeful that parasites and other beneficial insects from such a tropical region would be better adapted for establishment in Hawaii than material from colder zones such as Japan, North China or Korea. Accordingly on July 27, 1915, he took a steamer at Yokohama for Manila and by the middle of August was established at the College of Agriculture, University of the Philippines, Los Baños — an institution about 40 miles from Manila.

Meanwhile the *Anomala* problem at Honolulu Plantation Company and at the Oahu Sugar Company, Ltd., had become increasingly alarming. Great concern was felt for the future. The general tone of the correspondence over this problem at that time indicated that the planters were becoming impatient for some form of control at the earliest possible date.

Within a few weeks after his arrival in the Philippines Muir had success in finding certain parasites of white grubs in the soil which he considered worthy of careful attention. In a letter to the Director of the Experiment Station dated September 23, 1915, he mentioned observing a parasite then called *Scolia manilae* Ashm. flying over the cultivated fields at Los Baños by the thousands, and a few days later he wrote that this parasite would attack *Anomala* and *Adoretus* grubs in experimental tests he had conducted by confining grubs and parasites together in cages. He then concluded that this parasite was "promising" and plans were laid for its importation into Hawaii. Mr. Osborn went out to Los Baños in November of that year to assist in the work, remaining until July 1916. Muir remained until late in October 1916 and Dr. Williams went out in May 1916, and remained until October 1917. These men confined their attention primarily to *Scolia manilae* and strenuous efforts, involving much physical hardship in enervating tropical heat, were made to get it into Hawaii alive. In all some 30 shipments, consisting of many thousands of parasitized grubs or parasite cocoons, were sent and when Osborn returned he brought back a cage of adults in good condition. A total of 2164 living adults of this species was obtained for liberation into the *Anomala*-devastated areas on Oahu. These efforts were crowned with success for on September 16, 1916, this parasite was found to be well established in the *Anomala*-infested area and by January 1917, it had become exeedingly abundant and was effecting a heavy check on the grub population. By the summer of 1919 the entomologists reported the beetle so scarce as to be hard to find.

Several other *Anomala* parasites were studied by the entomologists and shipped to Honolulu from the Philippines. Of these one more species is known to be established. The circumstances attending its establishment are of much interest. In August 1916, Muir sent a consignment of cocoons of this parasite, *Tiphia segregata* Crawf., by freight from Los Baños. From it four females were

hatched in Honolulu; but no males were obtained and the four were not liberated. Following this, between August 1916 and March 1917, Williams sent 14 consignments of this parasite to Honolulu with disappointing results, since the insects usually arrived dead or mostly dead; but on the fifteenth attempt six females and a few males hatched out in good condition after the cocoons reached Hawaii.

These were liberated on Oahu Sugar Company lands on April 25, 1917. No further sign of this parasite was noted until August 1934, over 17 years later, when it was first seen on the wing at Oahu Sugar Company by J. S. Rosa. It was then found well established on the Island of Oahu and was parasitizing both the grubs of the *Anomala* beetle and the "Japanese beetle" (*Adoretus sinicus*). Actually it had become established in 1917, but had taken many years to become sufficiently adaptable to local conditions to become an efficient parasite. By 1935 it was contributing a very definite part in the control of *Anomala orientalis*.

Although *Scolia manilae*, now known as *Campsomeris marginella modesta* Sm., effected an excellent control of the *Anomala* beetle by 1919, the entomologists attempted the introduction of still more natural enemies during the ensuing years. Williams, returning from a two-year sojourn in Panama, Ecuador, British Guiana and Brazil, in which countries he made extensive and valuable entomological explorations, brought back to Honolulu on July 28, 1924, 16 living adults and 11 larvae of a large *Scarites* beetle, which he found predatory on white grubs and other soil insects in Brazil. These were liberated in a suitable place but failed to become established. Again, during June and July 1928, while Williams was in Missouri on other work already mentioned, he collected and shipped successfully to Honolulu 100 large Carabid beetles, *Scarites subterraneous* Fab., and *S. substriatus* Hald., which were known to be useful predators on white grubs in the soil.

These were liberated in the *Anomala* area on Oahu but neither species became established.

Early in 1930 the *Anomala* beetle increased in numbers in certain fields of Oahu Sugar Company to such an extent that it was feared by some that the established parasites were insufficient to hold the beetle permanently in check and that the outbreaks were more than temporary fluctuations in the normal equilibrium established between pest and parasite. It had spread entirely through the upper lands of this plantation and had also reached certain fields of Ewa Plantation Company. The possibility of obtaining still better control by new natural enemies was given attention again. A need for a thorough study of the beetle on Oahu was indicated also. F. A. Bianchi was added to the staff on June 30, 1930, and in October of that year was transferred to Oahu Sugar Company to undertake an intensive ecological study of the beetle and its parasite on this plantation. This investigation continued through May 1932. Van Zwaluwenburg also devoted much time to this general subject. As a result much precise data were assembled on the habits of the beetle and its parasite in relation to their environment, which in all, helped materially to explain the causes for the rise and fall of *Anomala* populations in localized areas.

In connection with these studies Van Zwaluwenburg and Professor H. A. Wadsworth, University of Hawaii, endeavored to determine the physical properties of soils both favorable and unfavorable to *Anomala* development since it was

observed early that certain soils were never infested while others were often heavily populated. Their studies ultimately resulted in the setting up of an empirical expression or formula, which they called the *Anomala* coefficient, by which any soil could be catalogued with respect to its susceptibility to *Anomala* infestation. Applying this formula to many soils resulted in the accumulation of many data which strongly suggest that many plantation soils in Hawaii could never be seriously populated with *Anomala* grubs even though the beetle eventually became established there.

This recurrence of *Anomala* damage in isolated spots in 1930, after 11 years of apparently perfect parasitic control, caused the entomologists to renew their search for more natural enemies. Pemberton visited Puerto Rico early in 1932 and investigated the tropical American toad, *Bufo marinus* (Linn.), which had been introduced into that Island 10 years previously and where it proved very useful in controlling certain sugar-cane pests somewhat similar to *Anomala orientalis*. He introduced 148 of these into Hawaii during April 1932. The toads multiplied rapidly and soon became well established. They were spread extensively in cane areas where *Anomala* was troublesome. Field studies indicated that they readily ate *Anomala* beetles and other insects in the cane fields.

Bianchi went to Guatemala in September 1932, where he investigated parasites of species of *Anomala* native to that country. This work continued through April 1935. Williams joined him for 9 months during 1934. They collected and shipped successfully to Honolulu large numbers of parasitized beetle grubs, from which a total of 1522 parasites was obtained, mated in the laboratory and liberated in *Anomala*-infested fields on Oahu. There were eight different species of grub parasites in the lot and there was every reason to expect establishment of at least one of these species, but the introductions failed. Early in January 1933, Bianchi observed a large wireworm in the soil in Guatemala which was highly predatory on beetle grubs. It was otherwise harmless. He and Williams later successfully introduced into Hawaii 5 lots of this insect, totaling 446 individuals, all of which arrived in excellent condition. Liberations were made in suitable *Anomala*-infested fields and there was ample reason to expect success in this venture. However, there is no evidence today that the species survived. This insect was previously unknown. Van Zwaluwenburg named it *Pyrophorus bellamyi*.

Bianchi returned again to Guatemala in 1941 and shipped more predatory wireworms of another species (*Pyrophorus radians* Champion), which it was hoped would prove better adapted for Hawaiian conditions than the first species. These were liberated in a suitable place during May 1942, but to date there is no evidence of the establishment of this species.

By 1936 the *Anomala* infestations subsided materially and to the present date (January 1945), no further difficulty has arisen over this pest on the sugar plantations.

It has spread very slowly and in 36 years is not known to be established anywhere more than 10 miles beyond the point where first seen. The entomologists and plant quarantine authorities have made every effort to prevent its movement from the infested area to other parts of the Territory of Hawaii. At the present writing the *Anomala* beetle may be said to be no longer a problem on the sugar plantations.

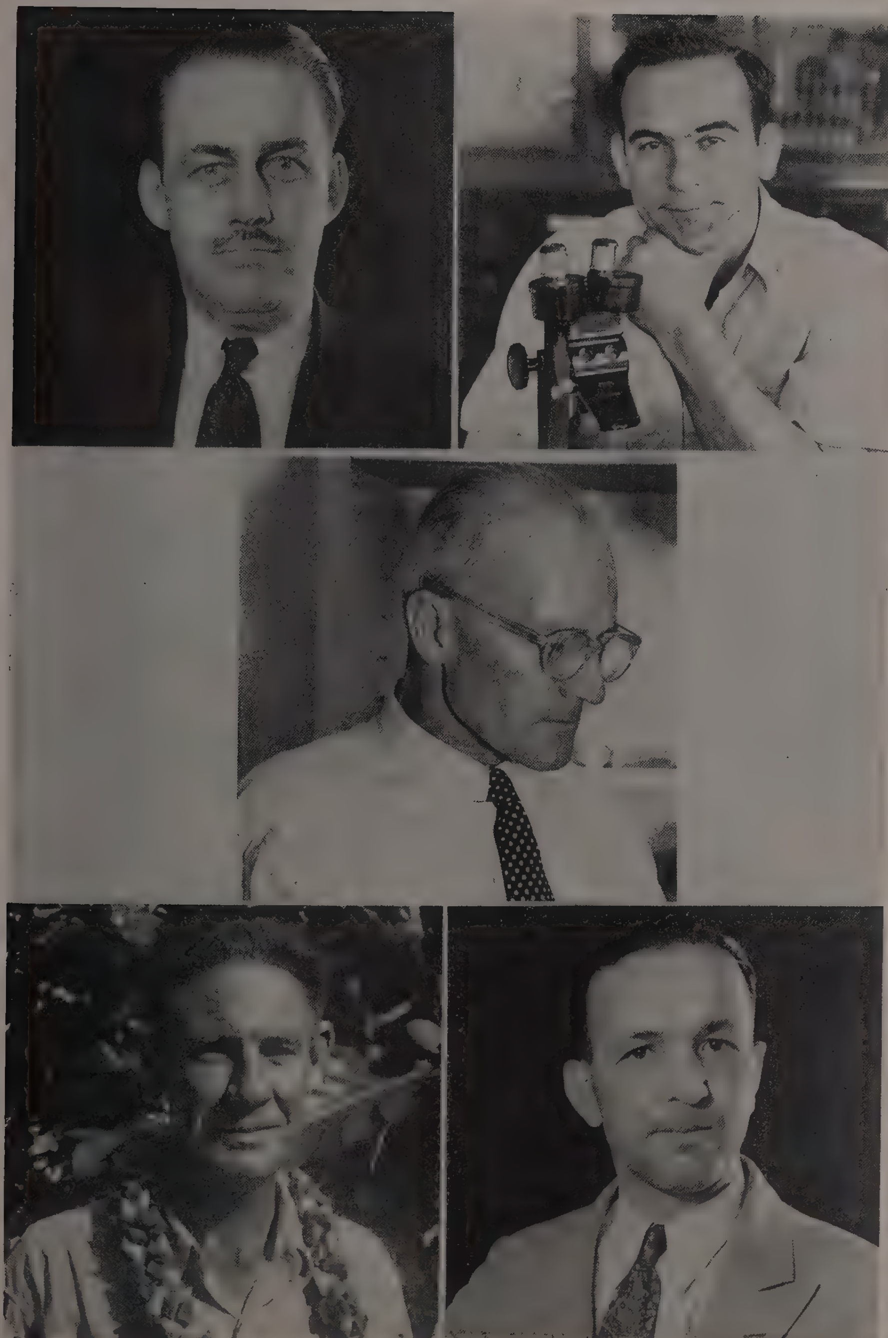

Fig. 6. Top: R. H. Van Zwaluwenburg and F. A. Bianchi. Center: C. E. Pemberton. Bottom: F. C. Hadden and J. S. Rosa.

Armyworms

(*Laphygma exempta* Wlk. and *Cirphis unipuncta* Haw.)

The two species of armyworms which periodically cause conspicuous damage to fields of young sugar cane in Hawaii are not native to the Islands. They entered the Territory sometime prior to 1899. Sometimes hundreds of acres of cane in the early months of growth have had the leaves stripped bare to the midribs by myriads of these caterpillars. The shocking appearance of such fields has always been a just cause for complaint by the planters, and the entomologists have given armyworms much attention. Before the organization of the Experiment Station, Koebele, while employed by the local government, brought into Hawaii many predatory insects and parasites from California and Mexico for the control of armyworms, some of which became established and proved very useful. As early as 1865 the botanist William Hillebrand, secured the mynah bird from India to help control cutworms and probably armyworms. However, satisfactory control was not effected and periodic outbreaks continued to appear on all of the Islands almost annually and in varying intensity.

In 1922 Osborn was in Mexico conducting certain entomological investigations for the Board of Agriculture and Forestry. Concluding his projects he was instructed by the Entomology department to search for armyworm parasites. Two years of such study resulted in his finding and shipping many consignments of parasites, mostly consisting of two species (*Euplectrus platyhypenae* How. and *Archytas cirphis* Curran), both of which became well established on all of the main Islands after liberation. It was felt at the time that these additions to the parasite complex improved the natural control of armyworms considerably.

In 1926 Mr. Rosa discovered a new egg parasite, *Telenomus nawai* Ashm., parasitizing the eggs of the commonest armyworm, *Laphygma exempta*, about the grounds of the Experiment Station, H.S.P.A. How it came to Hawaii is not known. Rosa reared many thousands of this parasite for distribution to all plantations requesting them, and some of the plantations started their own breeding laboratories in order to have quantities of this parasite on hand to distribute in their fields at a moment's notice. This work accomplished much good, but between 1926 and 1941 outbreaks persisted from year to year on many plantations, especially on the islands of Maui and Hawaii, and strenuous efforts were made to control the outbreaks with insecticides and chemical weed sprays, sometimes with good success. The outbreaks became exceptionally heavy during the latter part of 1941 and it was decided to renew the search for better parasites.

A seemingly small but nevertheless exceedingly important finding at this time influenced the entomologists in their work. The armyworm causing all of the damage in Hawaii in recent years was listed in 1899 in the *Fauna Hawaiiensis* under the name *Spodoptera mauritia* (Boisd.); Edward Meyrick, a British authority on moths, being responsible for the identification. This name was accepted in Hawaii until August 1937, when Swezey discovered by devious methods that this insect had been originally misnamed and that its correct designation should be *Laphygma exempta* Wlk. Another British authority, Sir George F. Hampson, had also corrected this mistake as early as 1909; but the record was obscurely buried in a voluminous published catalogue and overlooked by the Hawaiian entomologists until uncovered by Swezey. This disclosure had

an important bearing on the plans for future importations of armyworm parasites. Since our principal armyworm was now known to be a species of *Laphygma* instead of *Spodoptera*, attention was immediately drawn to *Laphygma frugiperda* S. and A., a species in the southern states of the mainland and known by Federal entomologists to have many parasites. Government entomologists had particularly investigated its natural enemies at Brownsville, Texas and had published extensively on the subject.

At that time Bianchi was in Guatemala on other entomological work. He was instructed to proceed to Brownsville, Texas, to investigate parasites of *Laphygma frugiperda* and introduce all of the important species into Hawaii. Arriving in Brownsville on April 22, 1942, he immediately began work and by April 16, 1943, had successfully shipped to Honolulu 13 consignments of parasites representing 6 species all new to Hawaii. Good numbers of each species arrived in excellent condition and were liberated in cane fields. Some were saved and multiplied in the laboratory and the progeny liberated. All were given a good opportunity for establishment. Williams and Rosa handled this work in Honolulu. Two of these parasites, *Apanteles marginiventris* (Cresson), and *Meteorus laphygmae* Viereck, became quickly established and by the summer of 1944 they were found widely distributed in many parts of the Territory. A third parasite *Eucelatoria armigera* (Coquillett) of American origin, which entered Hawaii by some mysterious method of its own prior to April 1942, has also become well established over Hawaii and has been shown by Van Zwaluwenburg to attack armyworms. These new parasites quickly brought results.

At the present writing armyworms are virtually non-existent over the whole Territory. This has been the situation for the past three years and it is hoped and believed that the new parasites have played an important part in bringing about this favorable condition.

The Chinese Grasshopper
(*Oxya chinensis* [Thun.])

The egg pods of the Chinese grasshopper probably came to Hawaii in soil with plants imported from the Orient sometime prior to 1892. It feeds mostly on plants of the grass family and occasionally does considerable damage to sugar cane. About 1928-29, damage to cane by this insect seemed to be definitely on the increase. Injury to cane of all ages was especially severe at Waianae Company. A need for some form of natural control was expressed by many plantation people. Pemberton undertook to accomplish this and on July 8, 1930, departed for the Malay Peninsula to study the natural enemies of this grasshopper and some half dozen other closely allied species occurring naturally there. Headquarters were established at Serdang, a small village about 175 miles up the peninsula from Singapore, where considerable areas of grasslands occurred and where grasshoppers could be sparingly found.

After seven weeks of work two species of egg parasites of *Oxya* grasshoppers were found. These were later determined by Timberlake as new species and named by him *Scelio serdangensis* and *S. pembertoni*. Pemberton shipped 13 consignments of these parasites to Honolulu between October 1930 and April 1931. Swezey and his associates handled the material upon arrival in Honolulu.

About 2600 living parasites hatched from the shipped material. Many were liberated and some saved for multiplication in the laboratory. This laboratory breeding of the parasites continued and by January 1933, the entomologists had reared and liberated 44,300 parasites. This project resulted in the establishment of *Scelio pembertoni* on all places where the grasshoppers were destructive. Since then to the present date no further conspicuous damage has been noted to cane on any of the plantations and no further damage at all has been reported from Waianae.

Mealy Bugs

Three species of mealy bugs commonly occur on sugar cane in Hawaii. They are all immigrants from other countries. Of the three the pink sugar-cane mealy bug, *Trionymus sacchari* (Ckll.), has been the most abundant. It has undoubtedly caused definite but obscure sugar losses to many, if not all, of the plantations for 40 or more years. In 1893 Koebele introduced a valuable lady beetle, *Cryptolaemus montrouzieri* Muls., from Australia to prey on mealy bugs in Hawaii. The introduction was successful and this lady beetle exerted a noticeable control over several kinds of mealy bugs, including the pink sugar-cane mealy bug.

However, satisfactory control was not effected until 1930, when F. C. Hadden found an important parasite of this mealy bug in the Philippines and successfully introduced it into Hawaii. This parasite, *Anagyrus saccharicola* Timb., was previously unknown and was described and named by Timberlake from material collected by Hadden in the Philippines and Pemberton in the Malay Peninsula. Swezey and associates reared the parasite in quantity and distributed it all over Hawaii. It became well established and has been an effective control over the pink sugar-cane mealy bug ever since. Hadden and Pemberton also found two species of lady beetles (*Pullus* sp.), which were important enemies of this mealy bug in the Philippines and the Malay Peninsula respectively. They were shipped in quantity to Hawaii, reared in the laboratory there and liberated in the cane fields; but like many other seemingly promising introductions, they were never seen again after liberation.

The gray sugar-cane mealy bug, *Trionymus boninsis* (Kuwana), is not an important pest on cane in Hawaii but in Louisiana it becomes so abundant as to be considered injurious. In 1909 Terry observed a parasite attacking it in Hawaii which may explain why this mealy bug is relatively uncommon.

This parasite, *Aphycus terryi* Full., was sent to Louisiana in 1932 by Swezey. From there it was spread to Georgia and Florida. It became established at all places and has proved of definite value in those States.

Of great interest was the discovery in Mexico in 1922 by Osborn of a parasite of the so-called avocado mealy bug, *Pseudococcus nipae* (Mask.). This mealy bug had been for many years exceedingly abundant in Hawaii on guava, banyans, edible fig, avocado and mulberry. Osborn introduced the parasite and several lady beetles during that year. The parasite, *Pseudaphycus utilis* Timb., a species previously unknown, became well established within a short time, together with one of the lady beetles, *Hyperaspis silvestrii* Weise, and in a few years the work of these natural enemies, particularly the parasite, reduced the mealy bug to such a degree that individuals of it were rarely ever seen again, and at the present time it is the opinion of some entomologists that the mealy bug has been actually eradicated.

The Mole Cricket
(*Gryllotalpa africana* Beauvois)

The mole cricket was known in Hawaii as early as 1896. It is of foreign origin and has a wide distribution within the Tropics. Since it burrows extensively in moist earth it may cause considerable leakage in irrigation ditches, walls of taro patches, reservoirs, etc. However, it also has the reputation of eating out the eyes of freshly planted "seed cane" and in poorly drained spots in some cane fields the damage may necessitate extensive replanting. Perhaps the greatest economic losses caused by this insect have resulted from damage to irrigation ditches.

Late in 1916, while Dr. Williams was engaged in *Anomala* work in the Philippines, he discovered the wasp, *Larra luzonensis* Roh., parasitizing this cricket at Los Baños. The patient and prolonged observation necessary to establish the relationship between this parasite and the cricket can only be appreciated by one engaged in similar investigations. With the discovery of the wasp and with a knowledge of its habits, which Williams worked out in detail, the problem of getting parasitic control of the mole cricket in Hawaii was greatly advanced. Dr. Williams was again in the Philippines on other work between October 1920 and April 1922. He had opportunity to study this parasite further and during 1921 was able to ship some to Honolulu alive. However it was unfortunate that only females emerged from the cocoons shipped and establishment of the species was impossible without both sexes being represented.

In February 1925, Pemberton went to the Philippines on other work, spending the first year at Los Baños. While there he was fortunate in finding a good lot of this parasite and in breeding up an abundance of material for shipment to Honolulu. During June and July he shipped 577 parasitized mole crickets from which good lots of wasps of both sexes matured in the quarantine room at the Experiment Station in Honolulu. These wasps were liberated by the entomologists in suitable places on Oahu and by September 1926, the parasite was found to be well established on the Island. Control of the mole cricket has since been considered satisfactory.

During 1921 Williams also observed at Los Baños a small active larrid wasp, *Notogonidea subtessellata* (Smith), which captured and parasitized small field crickets of the genus *Gryllus*. As *Gryllus oceanicus* Le Guillou is an undesirable species in both Hawaiian cane and pineapple fields, Williams made efforts to introduce this parasite into Hawaii. This he accomplished successfully early in 1922. The species became quickly established and has since been a useful enemy of the field cricket.

Wireworms

Two species of wireworms damage plant cane in Hawaii by eating out the eyes of the seed pieces or cuttings before they have an opportunity to germinate, or by boring into the bases and destroying germinating shoots. This damage is sometimes severe in the Hamakua District of the island of Hawaii and extensive replanting has been necessary to secure a good stand of cane in the damaged areas. These wireworms, *Simodactylus cinnamomeus* (Boisd.), and *Conoderus exsul* Sharp, are both of foreign origin and have been in the islands more than 45 years. The latter species has been the more troublesome of the two.

The entomologists first gave this problem attention early in 1920. Swezey reported the results of these investigations in *The Hawaiian Planters' Record* of July 1920 and of January 1922. No satisfactory chemical or cultural method was found to check the wireworms and the entomologists began in 1920, a long and disappointing search in foreign countries for parasites or other natural enemies of wireworms. As no effective wireworm parasite or other natural enemy was recorded in the world's entomological literature, the project was undertaken with full knowledge that complete failure was quite possible and even probable.

Williams left Honolulu on September 25, 1920, for the Philippines and Pemberton who was in Fiji at that time, left on December 9 of the same year for Queensland, Australia. Both made strenuous efforts to locate useful parasites or predators of wireworms in each country. Williams remained away until April 28, 1922, and Pemberton returned to Honolulu March 5, 1922. Though both accomplished other work of value to Hawaii while on these trips, the wireworm project failed. After a stay of a few months in Honolulu, Williams departed for South America on August 1, 1922, to continue the search for wireworm parasites. He traveled extensively in Panama, Ecuador, British Guiana and Brazil and did not return to Honolulu until nearly two years later. He succeeded in bringing back alive a number of large predatory beetles (*Glyptomorphus* sp.) which he found preying on soil insects such as white grubs and wireworms near Para, Brazil. These arrived in excellent condition and were liberated at Honokaa, Hawaii, August 20, 1924, but the insects apparently failed to become established. During his long stay in South America Williams made extensive collections of insects and amassed much information of reference value for the future.

Mention should also be made of the attempt by Williams to establish in Hawaii a large species of carabid beetle, *Scarites subterraneus* Fab., which he found in soil in Missouri in 1928. This was predatory on white grubs in Missouri and if established in Hawaii might prove useful against wireworms also. He introduced 102 of these beetles into Hawaii. They were liberated but have never been seen again. The wireworm thus remains one of the few pests of sugar cane that the entomologists have failed to check by biological methods. There is still hope that some day, somewhere, a suitable natural enemy may be found.

The Sugar-Cane Aphis
(*Aphis sacchari* Zehnt.)

The sugar-cane aphis is another insect of foreign origin which has been in Hawaii a long time. Koebele reported it on cane on Kauai as early as 1896. He introduced into Hawaii many aphis enemies from other countries before he became a member of the Experiment Station staff. Among these there were several lady beetles which became established and proved of such value in aphis control that no further introductions of aphis enemies were made until 1919 when Williams found the brown lacewing, *Eumicromus navigatorum* (Brauer) Kimmins, feeding on the sugar-cane aphis in Queensland. Realizing its value he returned to Honolulu August 19, 1919, with a good colony of this insect, together with living material of the lady beetle, *Coccinella arcuata* Fab. and *Coccinella repanda* Thunb., which he also found feeding on aphis in Queensland. Good lots of these

were reared at the Experiment Station insectary and liberated in cane fields. The lacewing became well established in a short time; but the lady beetles were never seen again after liberation.

In January 1923, Timberlake shipped from Whittier, California, a consignment of the aphis parasite *Lysiphlebus testaceipes* Cress. About 150 of these parasites arrived in Honolulu alive. They were immediately liberated and became well established and were found to parasitize the sugar-cane aphis, as well as other species. Both the lacewing and the *Lysiphlebus* have proved to be very useful natural enemies of the cane aphis.

No other intentional introductions of aphis enemies have been made and cane aphis outbreaks, such as were noted periodically by the entomologists for some 30 years, ceased after 1930. At present there are at least 16 insect enemies of the cane aphis in Hawaii.

Nematode Investigations

The possible relation of nematodes to growth failure of sugar cane led the entomologists in 1925 to undertake an elaborate study of this subject. This work was conducted by Muir, Van Zwaluwenburg and Dr. Gertrude Cassidy. One or more of this group was almost continuously engaged on this problem for the ensuing five years and a tremendous amount of information was assembled. Soil surveys were made on every sugar plantation in the Territory to determine the species of nematodes attacking the cane roots or in the soil about the roots, the extent of root damage, distribution and abundance of the various species, host plants other than sugar cane, natural enemies of nematodes in Hawaiian soils, response of certain of the important species to various environmental factors, etc. Life history studies were also made of the injurious species. The comprehensive nature of this project and the mass of accumulated data served to alleviate fears held by some that growth failure of sugar cane was caused primarily by these organisms. At most the work indicated that nematodes only constituted one of a large number of factors involved in the so-called growth failure of sugar cane.

This conclusion alone fully justified the money and effort expended in the investigation.

The Soil Fauna of Sugar-Cane Fields

A natural outgrowth of the nematode investigations was a study of all microscopical animal life in the soils of the Hawaiian sugar-cane fields. Such life consisted of insects, worms other than nematodes, spiders, mites, centipedes, millipedes, crustacea, etc. This work, which was conducted by Van Zwaluwenburg, covered a wide field and placed on record much exact information, previously unknown, respecting the many organisms present in the soil, which included their identity, food habits, movement in the soil, relative abundance and distribution at various depths in both fallow and growing-cane soil, the effect of varying rainfall on certain of the insect populations, the injury caused to cane roots by some of these minute animals and their relative importance in the complex of factors contributing to growth failure.

Fig Insects

Many trees, vines and shrubs of the genus *Ficus* contribute heavily in the building of forest cover in most tropical regions. None occurs naturally in Hawaii though many species have been brought in as individual plants and propagated from cuttings for many years. Such plants do not produce fertile seed except through the assistance of certain special pollinating insects of the family Agaontidae and usually each species of *Ficus* can only be pollinated by a single species of fig insect associated with that plant and no other kind. When pollination is accomplished by the insect the fruits, or figs, become filled with viable seeds surrounded by juicy, edible pulp attractive to birds, which soon spread the seeds far and near and, in a sense, forestation by this particular plant becomes automatic. No such pollinating insects are indigenous to the Hawaiian Islands.

In 1921 Pemberton was assigned the problem of introducing into Hawaii the special pollinating insects of the two Australian trees, *Ficus macrophylla* Desf. and *Ficus rubiginosa* Desf. Fine specimens of these trees were growing in Hawaii but had never produced seed. He found the correct pollinating insects of these trees abundant at Sydney, Australia. These insects, *Pleistodontes froggatti* Mayr. and *Pleistodontes imperialis*, Saund., were successfully introduced into Hawaii during 1921 and 1922; the former for *F. macrophylla* and the latter for *F. rubiginosa*. Establishment resulted with both species and the trees began producing quantities of fertile seed within a few months after the pollinators were liberated. The insects spread to all the islands in the Territory where either of these trees had been originally planted. As a result of these introductions both species of *Ficus* have been widely planted in Hawaii from seedlings propagated in flats, from seed broadcast on the mountains from airplanes and by natural methods following the eating of the figs by birds.

Nut-Grass Insects

Nut grass or onion grass (*Cyperus rotundus* L.) is a plant pest in Hawaiian cane fields. It occurs widely in the tropics and is not native to Hawaii. While in the Philippines on other work Williams investigated the insects that attack this plant there. In March 1922 he shipped two kinds of borers that work in the stem and rootstock of nut grass. One was a small moth, *Bactra truculenta* Meyr., and the other a weevil, *Athesapeuta cyperi* Marsh. Both were capable of killing these plants outright or badly injuring them by hollowing out the stem or entering the tubers. These insects were not known to attack other plants except sedges closely allied to the nut grass. However, since the insects were strictly phytophagous, or plant feeding, it was considered advisable to test them on sugar cane, pineapple and other economic plants in Hawaii before liberation. This was done with all of the insects of Williams' shipment. They failed to live or breed on any of these plants and died accordingly. They were thus considered safe for introduction.

Pemberton was the next Station entomologist to visit the Philippine Islands. Using the advance information obtained by Dr. Williams, Pemberton was able in April 1925 to assemble a shipment of both the moth and weevil and send it to Honolulu satisfactorily. The material arrived alive and was liberated

in nut-grass affected areas. The insects became established and though they have accomplished nothing spectacular, their constant attack on nut grass at times proved economically useful in certain areas.

Work on Other Insect Pests

Cockroach Parasites:

While engaged in other work in the Philippines during 1917 Williams observed a small ampulicid wasp, *Dolichurus stantoni* (Ashm.), which parasitized small roaches in the field. He succeeded in introducing this parasite into Hawaii the same year. Liberations resulted in establishment and the species rapidly spread to all the main islands. Then in 1940 while visiting New Caledonia he had the good fortune to capture and study the large brilliant blue-green wasp, *Ampulex compressa* (Fab.), which had habits somewhat similar to those of the Philippine parasite. However, its prey was the large brown roaches familiar to most housewives. He brought living material of this parasite back to Honolulu by plane a few months after finding it and had success in rearing it in the laboratory in sufficient quantity for suitable liberations. It soon became well established. Both of these wasps now play a definite part in checking certain species of cockroaches in Hawaii.

Parasite of the Torpedo Bug — Siphanta acuta (Walker):

The so-called torpedo bug probably came to Hawaii from Australia and was very common in the Hawaiian Islands at the time of the organization of the Experiment Station. It attacked a long list of plants, including both native and introduced species. At that time it was so common that the egg masses could often be seen in quantity on various plants and even on the sides of buildings, and the insects would be clustered thickly at and near the tips of the branches of their many host plants. Coffee, mango and citrus trees were especially favored by this insect. While Koebele and Perkins were in Queensland in 1904 they found the eggs of *Siphanta* species heavily attacked by parasites and in October they sent a consignment of parasitized eggs of *Siphanta acuta* to Honolulu. These arrived on October 19. On October 21 and 22 a total of 60 parasites emerged from the imported eggs. These were liberated in Nuuanu Valley, Honolulu and the species became well established and has proved so effective that the torpedo bug is no longer a conspicuous pest anywhere in Hawaii. Perkins found this parasite to be new to science. He described it under the name *Aphanomerus pusillus*.

Enemy of Coconut Scale (Pinnaspis buxi Bouche):

The coconut and several other palms in Hawaii are often badly infested with this scale insect. During 1935 and 1936 many coconut palms about Hilo and at Hanalei, Kauai became so badly attacked that they appeared dead. The scale is an immigrant to the Islands. When Swezey was in Guam in 1936, he learned of the importance of a small lady beetle, *Telsimia nitida* Chapin, there as a predator on a coconut scale *Aspidiotus destructor* Sign. Swezey sent 2 consignments of this lady beetle to Honolulu in November 1936 and one shipment in December. Nearly 200 of these beetles arrived alive in November and were

liberated in suitable places. The species became established and in a few years had so completely controlled the coconut scale wherever it occurred that it may now be listed as an insect of very minor importance in the Territory.

Parasite of Fern Weevil (Syagrius fulvitarsis Pasc.):

This weevil is highly destructive to many kinds of ferns and has killed off much of the large *Sadleria cyatheoides* ferns in the mountains back of Honolulu. It is of Australian origin and was known on Oahu as early as 1903 (W. M. Giffard. Proc. Haw. Ent. Soc. Vol. 2, p. 208, 1912). It was carried to the island of Hawaii in ferns by 1908. In September 1919 the weevil appeared in the beautiful *Sadleria* ferns that carpet the forest floor about Kilauea, Hawaii. A serious forest problem followed and destruction of the ferns was heavy. Efforts to eradicate the weevil by mechanical means failed. In April 1921 Pemberton undertook a search for the weevil in the forests of northern New South Wales. He found light infestations of ferns by this weevil in virgin forest areas on the upper tributaries of the Richmond River. The weevil larvae were found to be heavily parasitized and well controlled by a little wasp later described by Fullaway as *Ischiogonus syagrii*. Pemberton made two shipments of this parasite to Honolulu during May. A total of 319 parasites arrived in good condition. These were immediately liberated on Oahu and at Kilauea, Hawaii, resulting in establishment. The parasite has since proved to be very useful in checking this weevil at Kilauea.

Work on the Horn Fly (Lyperosia irritans L.):

The horn fly is considered one of the most serious insect pests of cattle. It was first noticed on Oahu at the Kaneohe Ranch during February 1898. Koebele examined and identified the flies during April. This pest undoubtedly came with shipments of cattle from the mainland sometime during 1897. Much time and effort have been spent by Experiment Station entomologists in attempts to effect a satisfactory natural control of this fly. A considerable amount of this work has been in cooperation with the Territorial Board of Agriculture and Forestry and dates back to 1898. Koebele gave this problem particular attention. Between 1906 and 1908 he introduced several fly enemies from Arizona and Mexico, one of which *Eucoila impatiens* (Say) became established but proved of little value against the horn fly. Between 1909 and 1913 Koebele investigated the horn fly in Germany thoroughly and sent to Honolulu many consignments of insects useful in the natural control of this pest. Two of the species which he introduced (*Sphaeridium scarabaeoides* L. and *Hister bimaculatus* L.) became established. These beetles prey on the maggots of the fly. The extent of benefit attending their establishment has not been determined but they are definitely beneficial.

Other members of the staff who have given attention to horn-fly enemies in foreign countries are Osborn, Williams, Muir and Pemberton. Various natural enemies have been imported from the Philippines, Australia, Formosa and still more from Mexico following Koebele's original studies there. Few have become established. Osborn's introduction from Mexico in 1922 of the large Scarabaeid beetle, *Copris incertus* var. *prociduus* (Say), proved successful. This beetle breeds in manure in pastures. It scatters, aerates and buries the manure to such

an extent that the normal breeding of the horn fly is interfered with. This introduction has been of considerable value. In September 1923 Osborn introduced from Mexico another so-called dung beetle, *Onthophagus incensus* Say. This also became established but it was not until July 29, 1934, that this fact was determined. At this time Swezey found it in Kona, Hawaii and it has since been found to have a wide distribution on that Island. On February 22, 1940, Swezey also found this beetle thriving in cow dung in Makua Valley, Oahu. It should be listed as another control factor operating against the fly. Several other introductions of horn-fly enemies were made by Territorial and other entomologists. Some were successful, but there is a need for further work on this problem.

Parasite of the Black Widow Spider, Latrodectus mactans (Fabr.):

The black widow spider was first seen in the Hawaiian Islands in 1925. It has since spread to several Islands of the group, being most prevalent in the hot dry sections. In 1938 Dr. W. Dwight Pierce, senior curator of entomology of the Los Angeles Museum, and Associates, discovered in California a promising egg parasite of this poisonous spider. The Entomology department arranged with Dr. Pierce to have this parasite shipped to Hawaii. This was successfully accomplished during August 1939. Rosa undertook the rearing of the parasite at the Experiment Station laboratory and during the following 7 months raised and distributed over 32,000 parasites. To date we have positive evidence of the establishment of the parasite on the Island of Maui. There is every reason to believe this parasite will prove a valuable addition to the insect fauna of Hawaii. Pierce named this parasite *Baeus californicus*.

Parasites of Mediterranean Fruit Fly (Ceratitis capitata Wied.):

An allotment of sugar-processing tax funds from Hawaii made possible expeditions into Africa, South America and the Orient in 1935-36 to search for parasites of fruit and melon flies. Van Zwaluwenburg and Bianchi were loaned to the Federal Government for one year to conduct the work in Africa under the direction of the U. S. Bureau of Entomology and Plant Quarantine. They left Hawaii September 7, 1935, and each was gone over a year. Van Zwaluwenburg confined his explorations to tropical West Africa while Bianchi restricted his travels to the eastern side of the continent. J. M. McGough of the U. S. Bureau accompanied Van Zwaluwenburg. Bianchi's associate was Noel H. Krauss of Honolulu. A large amount of information on African fruit flies, their host fruits and parasites was obtained for both East and West Africa. Van Zwaluwenburg and associate succeeded in getting some 750 parasites to Honolulu alive, representing 12 species. However, after liberation they were never seen again. Attempts from East Africa to get parasites to Hawaii alive failed. Quarantine restrictions governing the method of handling the parasites en route to Hawaii from the east coast of the United States added greatly to the difficulties of this project.

On the credit side of these expeditions is the storehouse of information amassed on fruit flies and their parasites in Africa in addition to the fine reference collections assembled. Future workers on this problem will find the way well paved by these pioneer investigators.

Parasites of the Rice Borer (Chilo supressalis Walker):

During the fall of 1927 rice growers on Oahu noticed severe damage to their crops by a caterpillar which fed in the stems of growing rice. In March 1928 it was identified as an oriental rice borer. Since this is very closely allied to certain so-called moth borers of sugar cane, it was feared by some that it might attack cane as well as rice. The Entomology department accordingly assigned one of its entomologists, Mr. Hadden, to accompany D. T. Fullaway, Territorial entomologist, to the Orient in search of parasites of this pest. They left Honolulu March 21, 1928. Hadden reported finding this insect to be a major rice pest in Formosa, Southern Japan and along the central coast of China from Shanghai to Hong Kong. Many parasites were found and a large number of consignments consisting of egg and larval parasites collected in Japan, China and a few from Formosa, were sent to Honolulu from May to September of that year. These were handled at the Experiment Station H.S.P.A. by Van Zwaluwenburg and an entomologist from the Board of Agriculture and Forestry. Of the eight species of parasites introduced and liberated three became established. These were an egg parasite (*Trichogramma japonicum* Ash.) and two larval parasites (*Amyosoma chilonis* Viereck and *Dioctes chilonis* Cushman.) It was found that by the summer of 1929 a notable reduction in damage by the rice borer resulted from the establishment of these parasites. In February 1941 Van Zwaluwenburg reported finding *Dioctes chilonis* also parasitizing the sweet potato stem borer (*Omphisa anastomosalis* Guenee), which is a serious pest of sweet potatoes in Hawaii.

Parasites of the Pepper Weevil (Anthonomus eugenii Cano.):

On February 24, 1933, a small weevil was found badly damaging bell peppers and chili peppers in Honolulu. It was soon found in many parts of Oahu and later spread to all of the main Islands of the Hawaiian group. Of Mexican origin, it was also known in Southern California, New Mexico and Arizona. While Bianchi was in Guatemala in 1934 on other work he investigated parasites of this weevil in that country. Four kinds were found and shipped to Honolulu. Of these, two species were liberated and became established. These were the pteromalid, *Catolaccus hunteri* Cwfd., and the eupelmid, *Eupelmus cushmani* (Cwfd.). In addition to parasitizing the pepper weevil Swezey found in 1937 that the *Eupelmus* also parasitized the common seed weevil, *Bruchus sallaei*. Later Bianchi reported the sweet potato weevil, *Euscepes postfasciatus* (Fairm.), as a host. One of the other parasites which Bianchi shipped from Guatemala was a promising Braconid, *Urosigalphus schwarzi* Cwfd., but all of the individuals surviving the trip were males. The future importation of this species should be attempted when opportunity is afforded. The ground work has been completed by Bianchi. This project has had the cooperation of Territorial entomologist Mr. Fullaway, who handled the material shipped by Bianchi.

Natural Enemy of the Carpenter Bee (Xylocopa varipuncta Patton):

Another assignment taken by Bianchi while in Guatemala was the problem of finding effective parasites or other natural enemies of the carpenter bee which has been damaging telephone poles, fence posts, redwood buildings and other

wooden structures in Hawaii at least since 1879. It appears to be native to Southwestern United States. Allied species occur in Guatemala. Bianchi found a large meloid beetle (*Cissites auriculata* Champion) whose larvae developed in *Xylocopa* nests and prevented the bees from maturing therein. During January and February 1935, he sent two large consignments of this beetle to Honolulu. Very large quantities of active beetle larvae were obtained from these shipments and liberated in carpenter bee nests on Oahu. There was every reason to believe this venture would prove successful, but to date there is no evidence that the beetle has become established.

Quarantine

The Experiment Station entomologists have always cooperated closely with the Territorial Board of Agriculture and Forestry in the development and operation of the Division of Plant Quarantine and, as previously mentioned, all but one of the original entomology staff at the Experiment Station were employed by the Board at the time they entered the service of the Experiment Station. Since then the Board has several times issued honorary commissions to several of the Experiment Station entomologists in order the better to utilize their particular talents in an advisory capacity, especially with respect to quarantine matters. In this the Station has further served the Board for many years through the separate appointments of Dr. Lyon, Mr. Agee and Mr. Pemberton as Commissioners, none holding office coincidently. At present Dr. Swezey holds a commission as Honorary Entomologist, while Dr. Williams and Mr. Pemberton are commissioned as Honorary Consulting Entomologists, all serving without pay.

The Station entomologists have played an important part in the proceedings of the sugar-cane quarantine committee, especially in the disposition of the many new varieties of cane imported from other parts of the world and held at the Molokai Sugar-Cane Quarantine Units.

During March 1936, the Pan American Airways inaugurated regular transpacific airplane service between San Francisco and Manila with stops at Honolulu (Pearl City), Midway, Wake and Guam and later this route included Hong Kong. Additional service began in July 1940, between San Francisco and New Zealand via Honolulu, Canton Island, New Caledonia and later Fiji. The danger of these planes bringing injurious insects into Hawaii was immediately recognized. In point of time Hawaii was brought close to tropical lands densely populated with many thousands of species of insects not already in the Territory, many of which would undoubtedly thrive in the Islands if given the opportunity.

For the protection of the Hawaiian sugar industry Dr. Lyon, Director of the Experiment Station, proposed the establishment of a quarantine station at Midway and later at Canton Island, at which points all transpacific planes stopped en route to Hawaii from either the Orient or New Zealand. All concerned were in favor of this proposal and accordingly an entomologist was stationed at Midway on November 25, 1936, with instructions to spray and inspect all planes stopping there. A similar station was established at Canton Island on April 16, 1940, when the route to New Zealand was started. These two stations were in constant operation and, until the beginning of the present war, no plane passed through these places without treatment. The entomologists

who served for varying periods at these stations were Messrs. Hadden, Williams, Van Zwaluwenburg, Bianchi, Charles A. Ely, D. B. Langford, and Richard R. Danner.

Following the outbreak of the war the armed forces took over the spray treatment and inspection of overseas planes arriving at Honolulu from various places. However, the identification of all insects found on these planes continued as a regular duty of the Experiment Station entomologists, and thousands of insects have been brought annually to the Station for identification. The information has been tabulated monthly and distributed to the Army and Navy medical authorities and to other interested government agencies. The regular and orderly accumulation of these data and the circulation of the facts to the proper authorities have had a favorable and stimulating effect on the officers charged with quarantine duties.

As part of the Station quarantine policy of being forewarned against all risks to the sugar industry incident to the operation of transpacific airplanes, it was deemed advisable to have firsthand information on the insect pests of the Island of Guam, since planes from the Philippines to Honolulu stopped at Guam. Such a survey was made by Swezey, assisted part of the time by Dr. R. L. Usinger and E. H. Bryan, Jr., of the Bernice P. Bishop Museum and by Mrs. Swezey during the entire visit. Dr. and Mrs. Swezey arrived in Guam April 27, 1936, and remained until the end of November. A very large and representative collection of the insects of that Island was made. Swezey and other specialists have identified much of this material, which is discussed in detail in Bulletin 172, Bernice P. Bishop Museum, entitled Insects of Guam — 1. This comprises 218 pages of descriptive matter of great reference value to entomologists. Swezey also gave an account of the insect pests of economic plants in Guam, which appeared in *The Hawaiian Planters' Record*, Vol. 44, No. 3, pp. 151-182, 1940.

In addition to Swezey's survey of Guam, it was felt necessary to have all possible information on the insects of New Caledonia when it was learned that the Pan American Airways planned to include that Island in their plane service to New Zealand and return. Consequently Dr. Williams accompanied by Mrs. Williams went to New Caledonia July 3, 1940, and continuously collected and studied the insects of the Island until November 12. A large and representative collection of insects was made and a valuable reference report on the many species of economic importance was published in *The Hawaiian Planters' Record*, Vol. 48, No. 2, pp. 93-124, 1944. Both the collections of Williams and Swezey have since proved highly useful in the identification of insects taken from planes arriving from the south seas. These surveys were also of great value in giving us exact information respecting the insects attacking sugar cane in those regions.

Some Disappointments

Introduction of Rose Beetle Parasites:

In attempting to control insect pests by natural or biological methods many disappointments and failures are the inevitable lot of the entomologist. Few, if any, of the successful achievements in this field of work by Hawaiian entomologists have been entirely free from disheartening periods and defeat at one time or another, while some of the projects have never been crowned with success. We

have already touched briefly on some of these. There are others in which promising natural enemies have been found and introduced into Hawaii without becoming established. The accumulated data on each project which failed are, however, available to the worker at a later date and his problem will be materially assisted thereby. A review of the work of the Department would be incomplete without a brief account of some of the difficult projects undertaken by the entomologists which did not terminate successfully.

Efforts to control the Chinese rose beetle, *Adoretus sinicus* Burm., with natural enemies is a good example. This beetle, formerly known in Hawaii as the "Japanese Beetle", came to the Islands from the Orient sometime before 1896. It has been an unmitigated nuisance ever since because of the damage it does to the foliage of a large variety of economic and ornamental plants. Apart from the work by Muir, Williams and Osborn in the Philippines during 1915-16 on the *Anomala* problem, which resulted in the establishment of two *Anomala* parasites in Hawaii which also parasitized the grubs of the rose beetle and accomplished a certain measure of control, three separate expeditions were sent out by the Experiment Station for the sole purpose of obtaining better biological control of this pest. The success with the *Anomala* beetle strengthened the feeling that similar control could be effected on *Adoretus sinicus*.

On May 20, 1927, Hadden was sent to Formosa where at least two *Adoretus* parasites were known. One, a species of *Tiphia* was a parasite of the grub and the other was the interesting tachinid fly, *Hamaxia incongrua* Walk., which parasitized the adult beetles. Hadden made 9 shipments of cages containing adult *Tiphia* wasps or *Adoretus* beetles parasitized in part by the tachinid fly. He returned on October 14 of the same year with a tenth lot. From these large consignments a total of 895 *Tiphia* wasps reached Honolulu alive and only about 38 of the flies. Part of the *Tiphias* was liberated and part saved for breeding. All of the flies were placed in a large cage with *Adoretus* beetles for breeding and one generation of about a dozen flies was obtained; but the colony died out and the imported *Tiphia* was never seen again after liberation. During part of the time Mr. Fullaway cooperated with Hadden in Formosa on this project.

The following year (1928) while Hadden was in Japan with Fullaway on the rice borer work already discussed, further attempts were made to get these two rose beetle parasites to Honolulu alive. Mr. Rosa went out to Formosa in September to help in this work, returning in November with cages of the parasites. Seven consignments of well-stocked cages were received in Honolulu that year from Hadden, Fullaway or Rosa and liberations were made of both parasites; however, no establishment of these insects resulted. During 1929, Van Zwaluwenburg was in Java attending the Pacific Science Congress. At the conclusion of the Congress he went to Japan and made four large shipments of beetles in an effort to get the parasite (*Hamaxia*) to Hawaii alive. Some living flies were obtained from this material, but attempts to breed them in cages at the Experiment Station failed.

Of the several parasites which Muir, Williams or Osborn found parasitizing *Adoretus* grubs in the Philippines during 1915 and 1916, the scoliid, *Tiphia lucida* Cwfd., and two tachinids, *Prosena* sp. and *Dexia* sp., were considered important. The tachinids were also parasitic on *Anomala* grubs. They succeeded in shipping good quantities of these to Honolulu during 1916 and 1917 and liberations in the

field were made but none became established. On May 15, 1930, Hadden was sent to the Philippines to attempt large shipments of the *Tiphia*. Between September 1931 and November 1932 he sent some 24,000 parasitized *Adoretus* grubs to Honolulu from Los Baños. Many of the grubs and developing parasites decayed en route from Manila but from the entire lot a total of over 2,400 parasites was obtained for liberation in good localities on Oahu. Again there is no evidence that this parasite became established.

Slow transportation by steamer over great distances has been one of the greatest obstacles encountered in conducting this and much other work of the same nature. The future offers great advances in this respect through the development of transoceanic airplane service.

Importation of Mosquito Enemies:

Mosquitoes have many natural enemies in various parts of the world. A few that are not strictly specific enemies are in Hawaii such as dragon flies and the introduced "top minnows". These accomplish a great deal of good, but there is much more that can be done in this field in the future. The Experiment Station entomologists have never been required to confine their work solely to sugar-cane pests and when in foreign countries have always kept an eye out for any beneficial insects which might prove useful in Hawaii. While Pemberton was on the Island of New Britain in 1929 he investigated the predacious mosquito, *Megarhinus inornatus* Walk., commonly referred to as the "Cannibal Mosquito". The larvae of this and many other mosquitoes of the same genus feed upon the larvae of mosquitoes developing principally in pockets of water occurring above ground such as tree holes and many artificial containers. About the town of Rabaul the *Megarhinus* appeared to be a useful control factor against day-flying mosquitoes. Pemberton made two shipments of the larvae of this mosquito and brought a third lot on August 30, 1931. These arrived in good condition and several hundred larvae were used in efforts to get the species established in upper Manoa Valley and on the mountain of Tantalus. The species went through several generations in water barrels set out for its convenience in the forest but it gradually died out and six months after the last importation it disappeared entirely. This was very disappointing since the adult mosquito was incapable of biting or sucking blood and its larvae were highly destructive to the larvae of other mosquitoes.

When Pemberton was in the Malay Peninsula in 1930 he was impressed with the abundance and voracious manner in which a Notonectid bug, *Anisops* sp., fed on mosquito larvae in small ponds, lakes and particularly in temporary pools inaccessible to fish. Returning to Honolulu in May 1931, he attempted to bring a colony of this insect in jars of water containing mosquito larvae for food. The steamer was grounded near Hong Kong and the delay in transshipment resulted in all the insects dying a few days before reaching Honolulu. There has been no further opportunity to repeat this introduction.

In 1940 Williams observed the water bug or pond skater, *Hydrometra aculeata* Montr., in New Caledonia commonly present on fresh water pools and quiet water bordering streams. It feeds on mosquito larvae and other small organisms that come to the surface. It is definitely a useful mosquito enemy. Williams planned to introduce it into Hawaii, but unforseen circumstances prevented this.

It is a problem worthy of attention sometime in the future. The information obtained by Williams on this insect will greatly advance the project if and when it is undertaken again.

Parasites of the Bean Butterfly:

The so-called bean butterfly, *Cosmolyce boetica* (L.), is of oriental origin and has been a pest in Hawaii at least since 1882. It is a small blue butterfly whose larvae feed upon the flowers, pods and seeds of many leguminous plants. During Williams' sojourn in the Philippines in 1916-17 and again in 1920-22 he examined caterpillars of allied butterflies for parasites. He found at least three different enemies. Returning to Honolulu in April 1922, he attempted their introduction. One, a species of *Apanteles*, which he found parasitizing *Thecla* caterpillars, failed to survive the long trip and all 39 which he brought died in transit. Another parasite was an ichneumonid wasp which he found parasitizing the caterpillars of the bean butterfly, *Catochrysops cnejus* Fab. Of 56 of these, eight survived the trip and were liberated in a suitable place, but failed to become established. A third bean butterfly enemy which Williams studied and brought back on this trip was the eumenid wasp, *Odynerus luzonensis* Bohwer, a species new to science. He discovered this wasp storing up lycaenid caterpillars in a burrow in the soil to serve as food for its developing young. Twenty-four of these wasps were brought safely to Honolulu and liberated, but there is no evidence that the introduction was successful. These are all beneficial insects that should be given further trial in the future when there is opportunity.

Insect Collections and Taxonomic Work

It has never been the intention of the Entomology department to take over any of the functions of a museum, but in the course of 41 years of biological control work, involving much travel in many foreign lands mostly within the tropics, some 200,000 or more specimens have been assembled for reference purposes, in addition to a very large and comprehensive collection of the insects that occur within the Hawaiian Archipelago, consisting of native, immigrant and introduced species. Special attention has been given to a collection of all known insects which attack sugar cane throughout the world. Particular mention should be made of the Koebele collection of lady beetles comprising several thousand specimens and his equally large and valuable assembly of Mexican beetles mostly named; the fine collection of Hawaiian lepidoptera made by Swezey; the many cases of Elateridae or click beetles from many parts of the world, which has been put in order, built up by exchange and mostly named by Van Zwaluwenburg, an authority on this family; the very large collection of miscellaneous beetles made by Hadden, much of which is named; the vast amount of carefully mounted, labeled and named microhymenoptera, representing years of patient labor and study by Timberlake; and the exceptionally useful reference collection of homopterous and heteropterous bugs assembled and named by Muir and Kirkaldy respectively. Much more has been added by Williams and Bianchi from South and Central America and a great deal from the South Pacific, Australia, and the Malay Archipelago, including the Philippines, by Muir, Williams, Pemberton, Perkins and Hadden. We have already mentioned Swezey's and Williams' con-

tributions from Guam and New Caledonia. Williams has also had a large hand in the building up of an important reference collection of many groups of parasitic hymenoptera, while in recent years Bianchi has gone far in the mounting, identification and ordered filing of a large collection of thysanoptera or thrips, most of which was collected by him. In the building of the Hawaiian collection, all members of the staff have played a part; but Swezey's contributions on the forest and lowland entomology, together with those by Perkins and Williams are outstanding.

Someone has well said that an insect specimen without a label is not worth as much as the pin on which it is impaled. Of the thousands of insects in the Station collection, very few, if any, are without labels indicating where collected, the collector, the date and often additional data to indicate the food plant of the insect or the insect host if it were parasitic or predatory. Rosa has carried on this tedious work, amongst other duties, for the past 28 years. The reference value of all of this material is tremendously enhanced if it is properly segregated into orders, classified, named and appropriately recorded in literature when considered necessary. The entomologists of the Experiment Station have not neglected this important division of work and have gained world-wide recognition in the field of taxonomy. The list of publications is far too great to include here and if assembled would comprise several thousand pages of invaluable descriptive matter, useful not only to the local entomologists but to the world at large. Prominent contributions in such work have been made by Kirkaldy, Perkins, Swezey, Muir, Timberlake, Williams, and others. As a reference book on Hawaiian sugar-cane entomology Williams' *Handbook of the Insects and Other Invertebrates of Hawaiian Sugar Cane Fields*, published in 1931, serves as a constant source of reliable information to all concerned with sugar-cane insects on plantations, in public schools and at the Experiment Station, and the demand for this book has been heavy from all other cane-sugar-producing countries.

Special mention should also be made of Timberlake's work with the Koebele collection of lady beetles, involving a whole year of concentrated study on this family of economic insects followed by publication in *The Hawaiian Planters' Record* of his findings (Vol. 47, No. 1, pp. 1-67, 1943).

Finally the *Proceedings of the Hawaiian Entomological Society*, published almost annually since 1905 and financed by the H.S.P.A., contains to date 5,299 pages of entomological matter mostly bearing on Hawaiian entomology throughout which the Station entomologists have been heavy contributors. This Society has met monthly at the Experiment Station since 1905 and its "Proceedings" may be said to form an important part of the activities of the entomology staff, and without the financial support of the H.S.P.A., and the active participation of the Station entomologists through the years, the Society would hardly have been able to exist or hold the high place in the estimation of entomologists in the outside world that it has enjoyed since the beginning. Dr. Swezey has served as Editor of the *Proceedings* from the start and is responsible in large measure for the excellence of form and accuracy of detail that has so characterized the *Proceedings* in every issue. After 37 years of such service he retired from this work and was succeeded by Mr. Van Zwaluwenburg. No entomologist in the Territory of Hawaii can do full justice to his work without access sooner or later to this publication.

Future Prospects

Forty-one years of work has enriched the Entomology department with much firsthand information respecting most sugar-cane insects over the world where cane is grown. There is also a broad understanding of what natural enemies they have or may have and in general where they may be obtained. Within the sphere of natural control, years of successes tempered with a fair share of failures, have left a heritage of experience and recorded facts invaluable to those who succeed the pioneer workers. With continued faith in the biological method of insect control they should be equally successful in meeting the problems of the future.

The Entomology Staff 1904-1945

Koebele, Albert	Appointed Consulting Entomologist August 1904. Died December 28, 1924.
Craw, Alexander	Appointed Consulting Entomologist August 12, 1904. Died June 28, 1908.
Kirkaldy, G. W.	Appointed Assistant Entomologist August 1904. Died February 2, 1910.
Terry, F. W.	Appointed Assistant Entomologist August 1904. Died November 7, 1911.
Swezey, O. H.	Appointed Assistant Entomologist August 1, 1904, Entomologist 1915-1933, Consulting Entomologist 1933-
Perkins, R. C. L.	Appointed Entomologist August 1904, Consulting Entomologist May 1, 1915-
Muir, F. A. G.	Appointed Assistant Entomologist September 1, 1905. Entomologist November 1, 1915. Died May 13, 1931.
Kershaw, J. C.	Appointed Assistant Entomologist January, 1910. Resigned November, 1912.
Osborn, H. T.	Appointed Assistant Entomologist July 1, 1913. Resigned August 31, 1917 to Enter Army. Reappointed Assistant Entomologist April 15, 1919. On leave of Absence August 24, 1921 to June 1, 1923. Resigned November 30, 1924.
Timberlake, P. H.	Appointed Assistant Entomologist January 11, 1916. Resigned May 21, 1924.
Williams, F. X.	Appointed Assistant Entomologist May 8, 1916, Associate Entomologist 1929-
Rosa, J. S.	Appointed Laboratory Assistant February 19, 1917. Resigned September 30, 1920. Reappointed November 21, 1921. Laboratory Technician 1936-
Pemberton, C. E.	Appointed Assistant Entomologist February 1, 1919, Associate Entomologist 1923, Entomologist 1928, Executive Entomologist 1932-
Van Zwaluwenburg, R. H.	Appointed Assistant Entomologist October 18, 1924, Associate Entomologist 1929-

Hadden, F. C.	Appointed Assistant Entomologist June 17, 1925, Resigned November 30, 1933. Served as Quarantine Inspector, Midway Island, November 16, 1936 to January 12, 1942.
Henderson, Gertrude (Mrs. M. Cassidy)	Appointed Assistant Nematologist August 5, 1925. Resigned September 8, 1926. Reappointed January 1, 1927. Resigned October 15, 1931.
Bianchi, F. A.	Appointed Assistant Entomologist July 1, 1930-
Langford, D.	Quarantine Inspector, Canton Island, December 1, 1939—September 30, 1940.
Danner, Richard R.	Quarantine Inspector, Canton Island, September 18, 1940—September 3, 1941.
Ely, Charles	Quarantine Inspector, Canton Island, September 16, 1941—March 16, 1942.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 16, 1947, TO DECEMBER 15, 1947

Date	Per Pound	Per Ton
September 16, 1947—December 15, 1947	6.32¢	$126.40

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